Graphics and Imaging Overview

Session 200

Graphics and Imaging Overview

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Graphics and Imaging Directions

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Agenda

- Graphics Architecture of Mac OS X
- PDF: Mac OS X's Digital Paper
- The GPU Computing Revolution
- What's New for Panther

Aqua

Frameworks

Graphics

Darwin

Aqua

Frameworks

Quartz

OpenGL

QuickTime

Quartz Compositor

Darwin

Aqua

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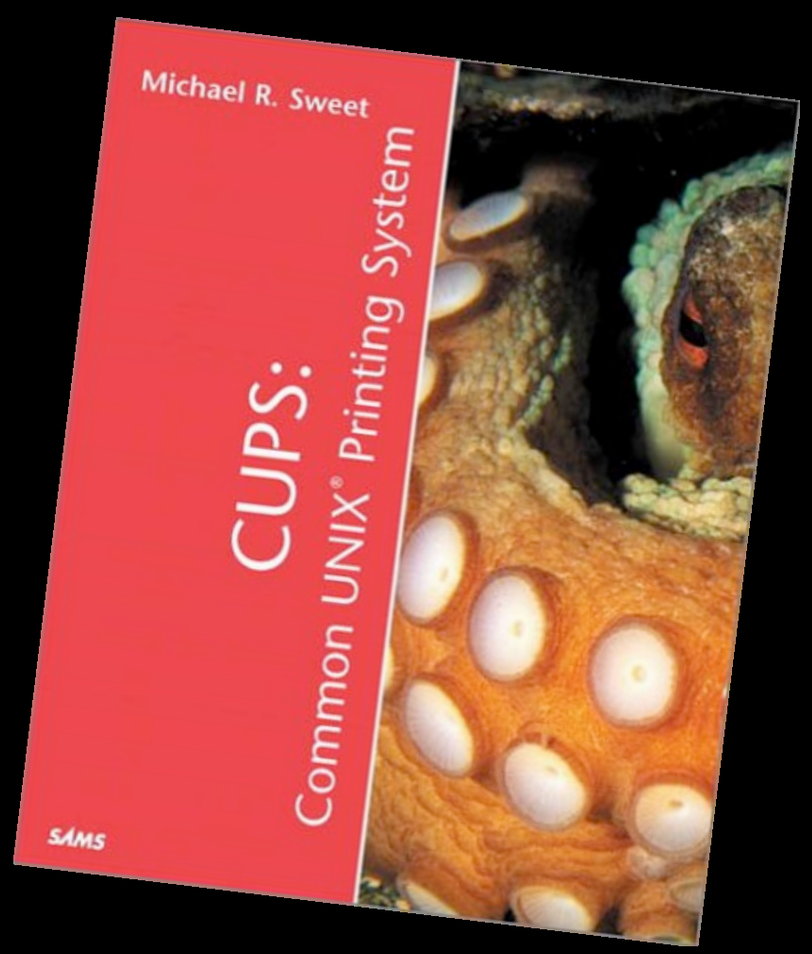
Industry Standard 2D Imaging Model

Quartz 2D

- Lightweight C Library
- Read/Write PDF
- Fast Anti-aliasing
- Destination Alpha
- Apple Type Services built-in
- Type 1 Scaler built-in
- ColorSync built-in

Printing With Quartz

- Same imaging model for Screen and Printing
- Spool file is just PDF
- High-quality Quartz rasterization for inkjets
- End-to-end color management
- Open Source infrastructure



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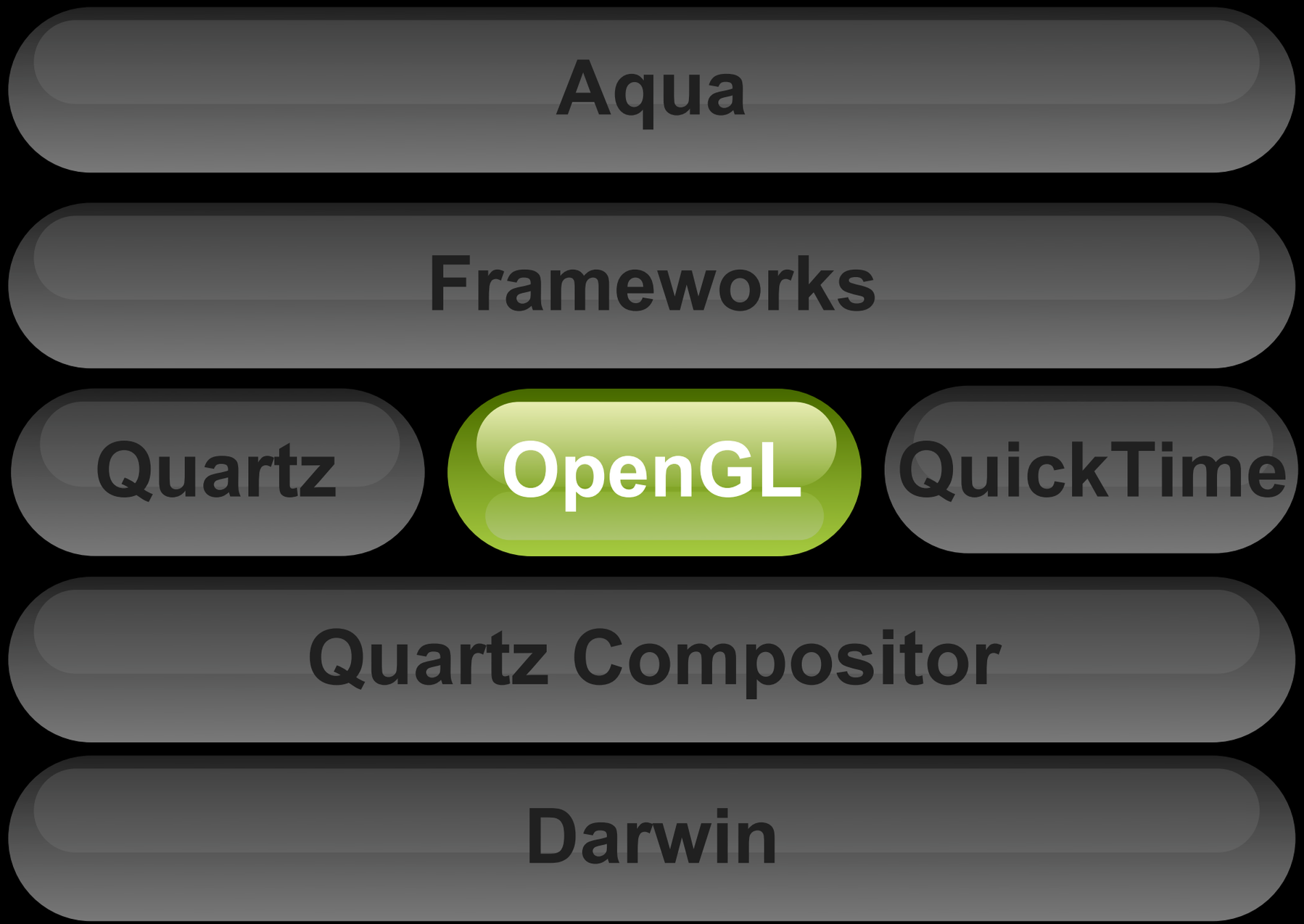
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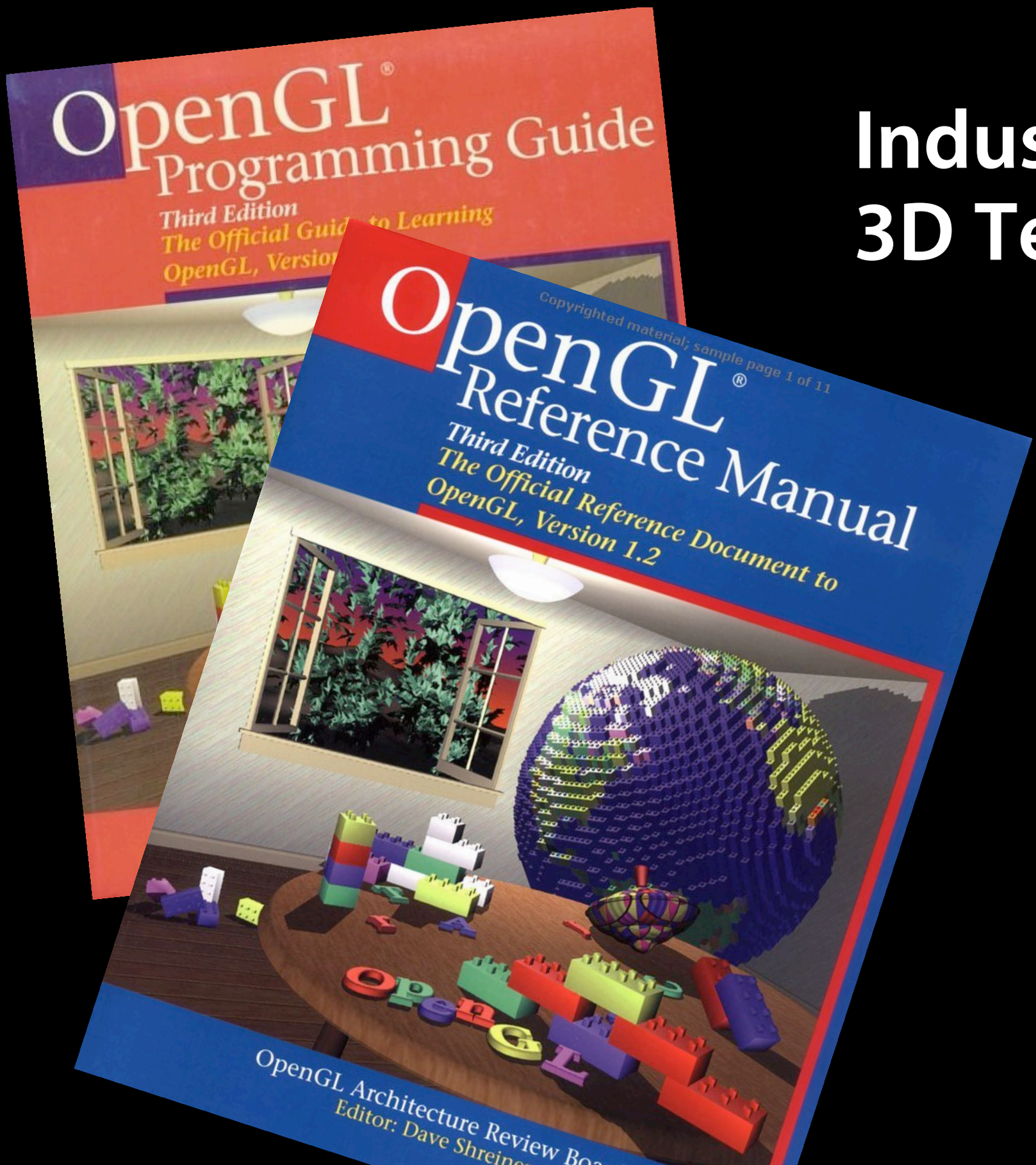


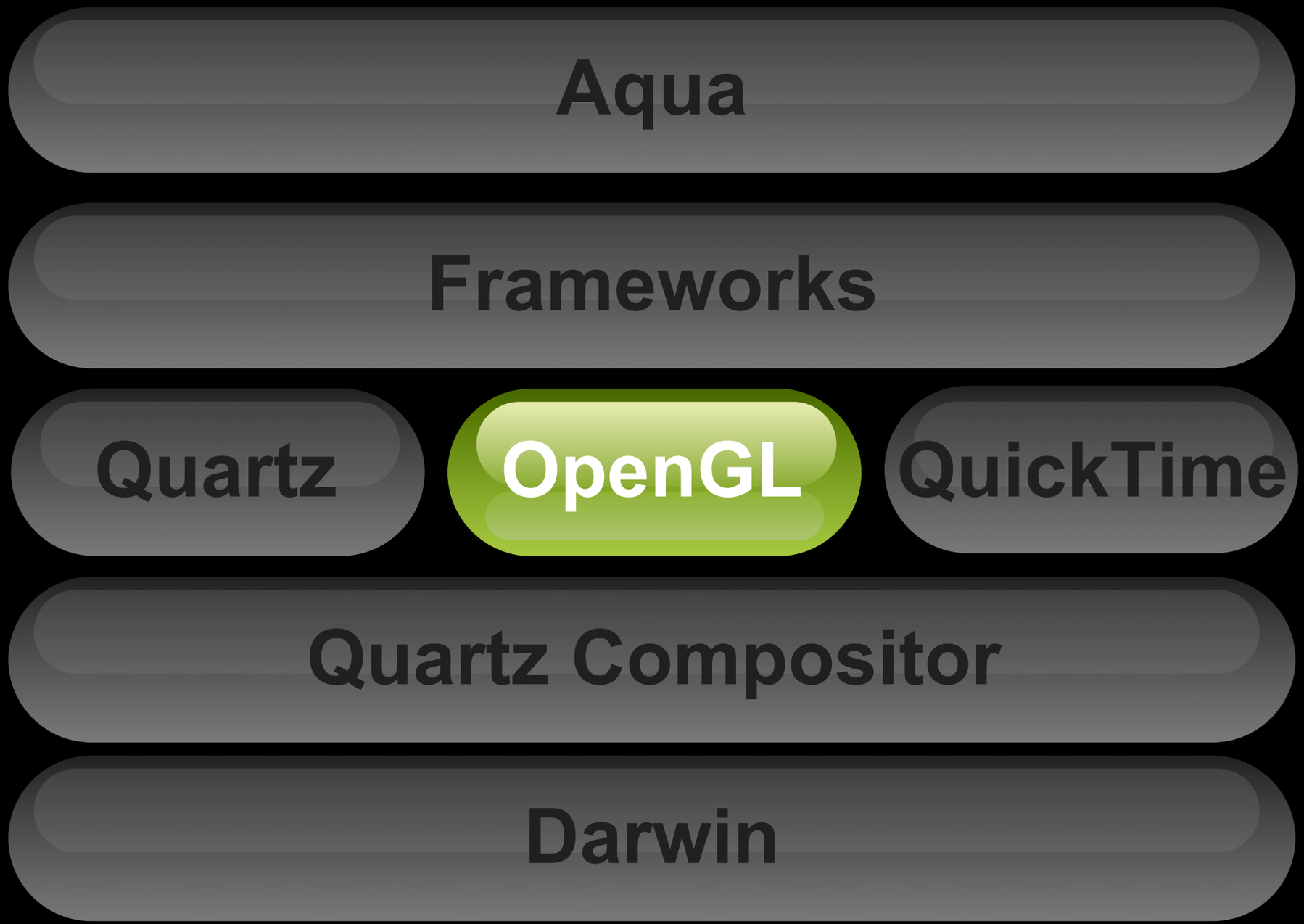
Industry Standard 3D Technology

Mac OS X OpenGL

- State-of-the-art architecture
  - Resource virtualization
  - Data flow optimizations
- Unified Driver Model
- Stability and Robustness
- Not just for games!

Mac OS X OpenGL

- Innovative uses of OpenGL in the OS
  - Quartz Extreme
- Innovative uses of OpenGL in consumer applications
  - Keynote, iChat
- Your app here next year!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Aqua

Frameworks

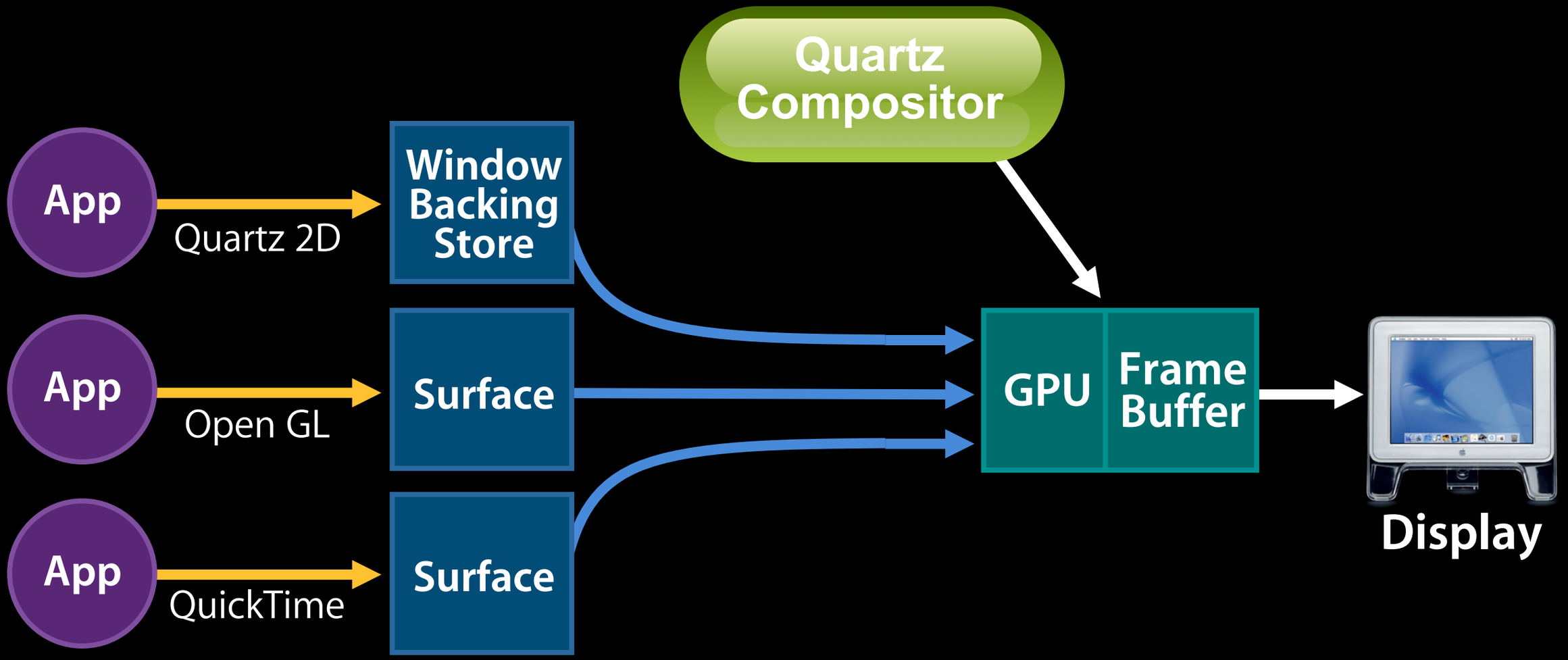
Quartz | OpenGL | QuickTime

Quartz Compositor

Darwin

Window System as a Digital Image Compositor

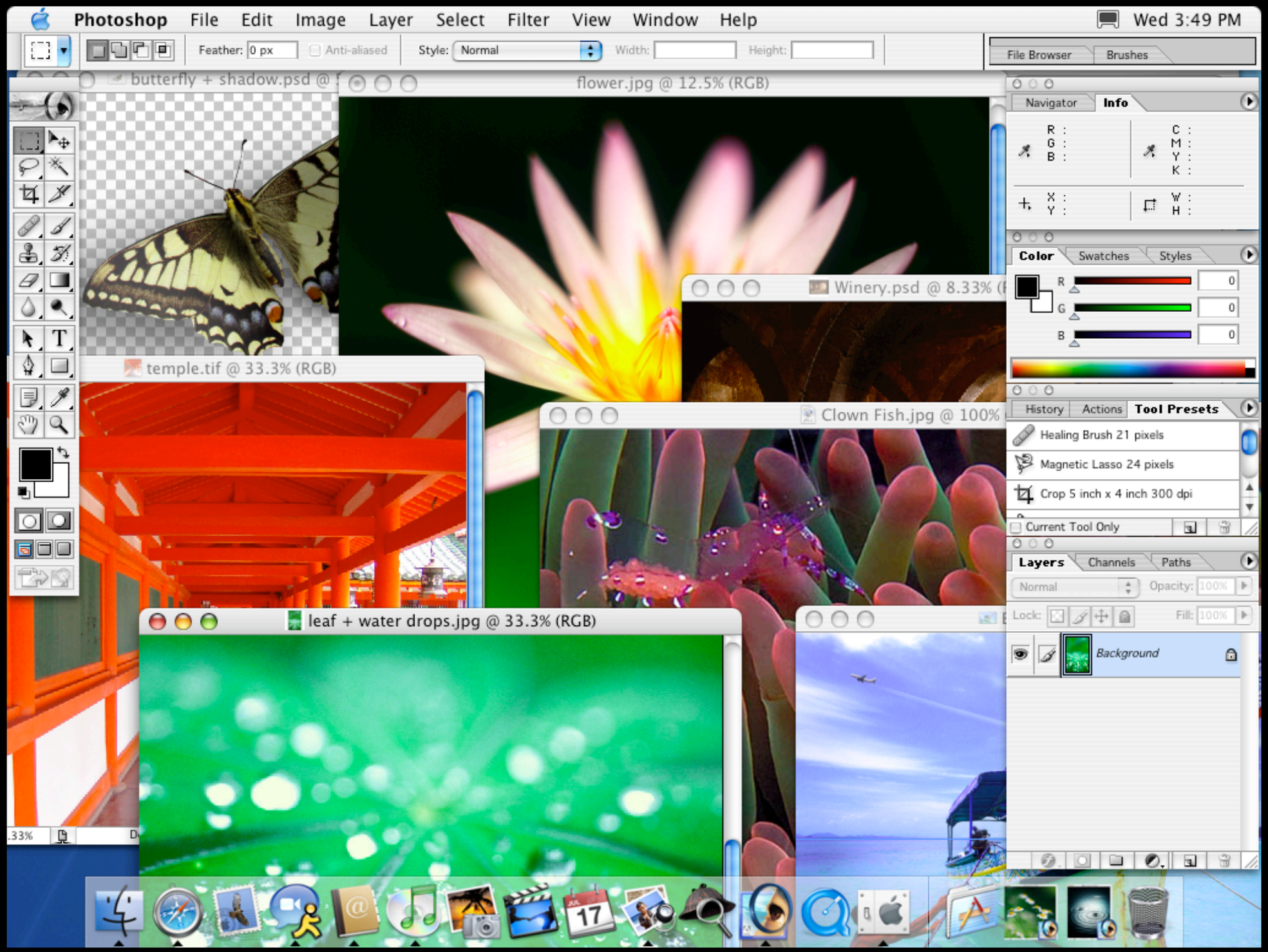
Quartz Extreme



Apple Leading the Industry

- Panther is our 3rd generation desktop composition engine
- Natural evolution of windowing systems
- Apple OpenGL is robust enough for 24x7 operation
- Our advances are directly useable by you via OpenGL

Exposé


Photoshop File Edit Image Layer Select Filter View Window Help
Wed 3:49 PM
Feather: 0 px
Anti-aliased
Style: Normal
Width:
Height:
File Browser
Brushes
butterfly + shadow.psd @
flower.jpg @ 12.5% (RGB)
Navigator
Info
R :
G :
B :
C :
M :
Y :
K :
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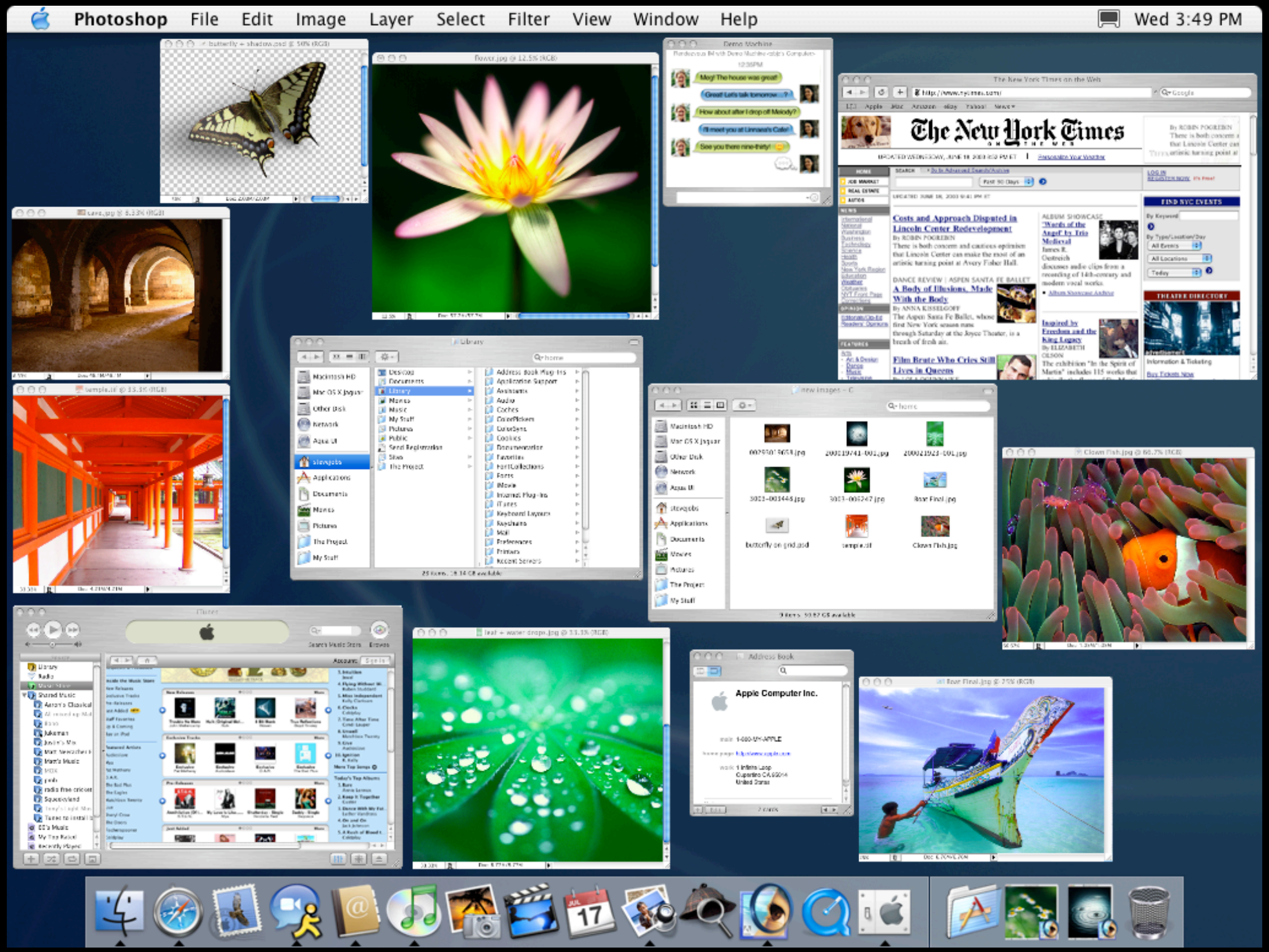
W :
H :
Color
Swatches
Styles
R
G
B
Winery.psd @ 8.33%
temple.tif @ 33.3% (RGB)
Clown Fish.jpg @ 100%
History
Actions
Tool Presets
Healing Brush 21 pixels
Magnetic Lasso 24 pixels
Crop 5 inch x 4 inch 300 dpi
Current Tool Only
Layers
Channels
Paths
Normal
Opacity:
Lock:
Fill:
Background
leaf + water drops.jpg @ 33.3% (RGB)

Exposé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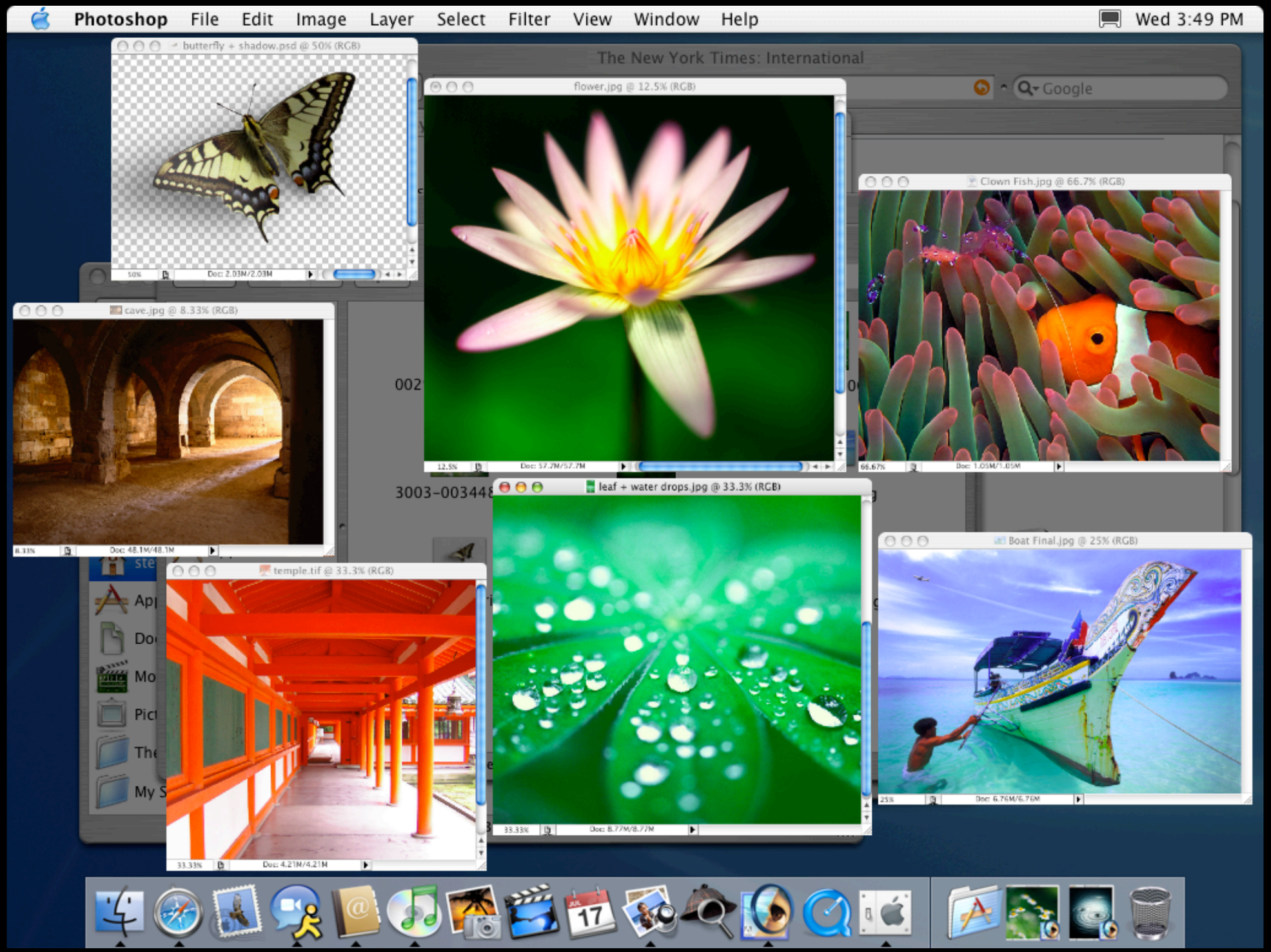
The New York Times
Costs and Approach Disputed in Lincoln Center Redevelopment
A Body of Illusions, Made With the Body
Film Brute Who Cries Still Lives in Queens
Apple Computer Inc.

Exposé


Photoshop File Edit Image Layer Select Filter View Window Help
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butterfly + shadow.psd @ 50% (RGB)
The New York Times: International
Google
flower.jpg @ 12.5% (RGB)
Clown Fish.jpg @ 66.7% (RGB)
cave.jpg @ 8.33% (RGB)
leaf + water drops.jpg @ 33.3% (RGB)
Boat Final.jpg @ 25% (RGB)
temple.tif @ 33.3% (RGB)

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PDF: Mac OS X's Digital Paper

Digital Paper

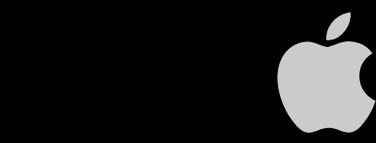
- PDF is a digital representation of the printed page
  - Application independent
  - Device independent
  - Extremely high fidelity
- 500 million viewers distributed
- Universal “view-level” abstraction in the MVC paradigm

MVC Paradigm

Controller

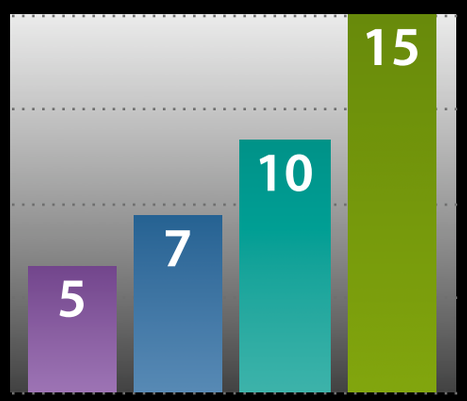
Model

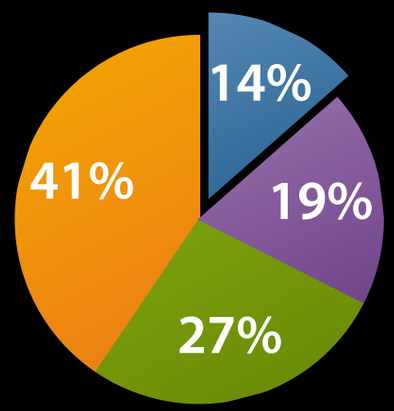
View

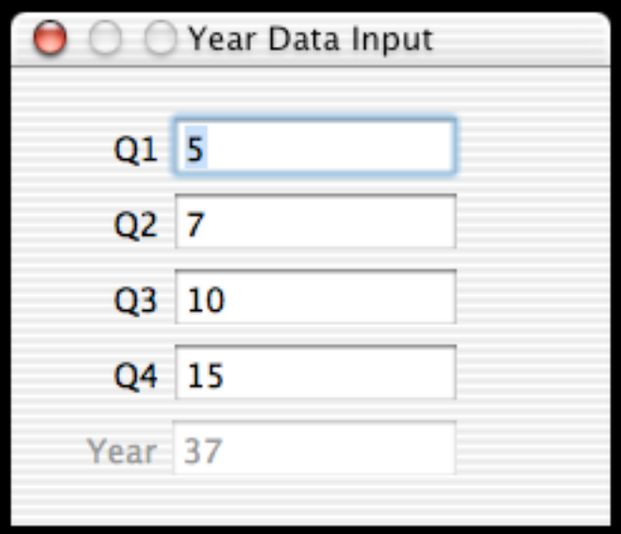


MVC Example

```
Q1 = 5,  Q2 = 7, Q3 = 10, Q4 = 15
Year = Q1 + Q2 + Q3 + Q4
```





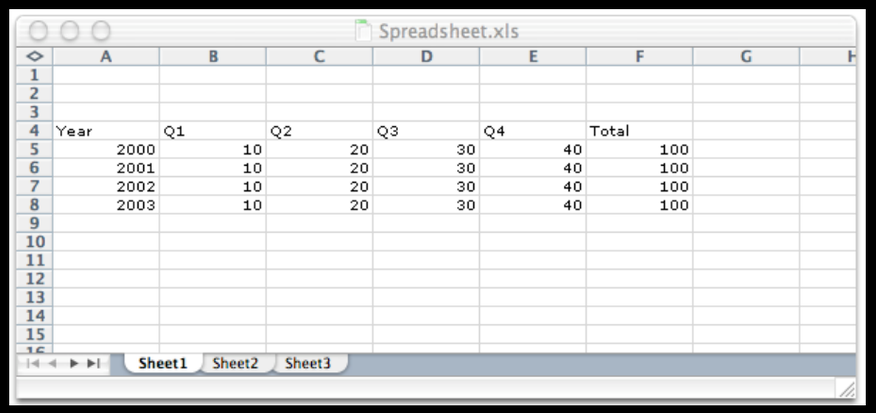


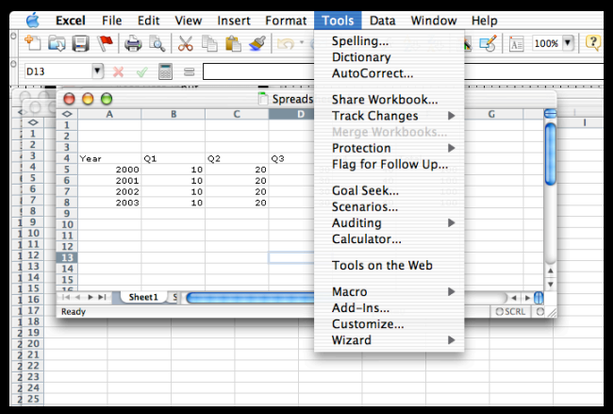
- Model: Application data structures
- View: Visual representation of model
- Controller: Manipulates model

The Value of MVC

- Models can have multiple views
- Models can have multiple controllers
- Any model can be “projected” onto a 2D representation
- Views of vastly different models can share a common visual language

Document-based Applications Are MVC





- Model: Application data structures, usually made persistent in document

- View: Visual representation of model in window

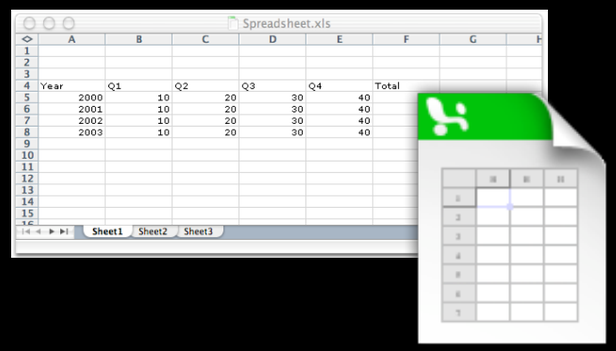
- Controller: User Interface of application

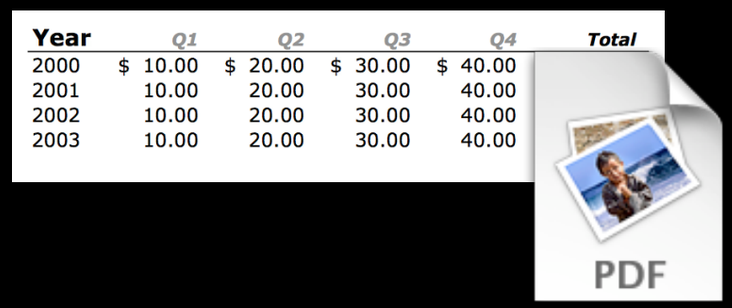
This Is Not a Spreadsheet

Year	Q1	Q2	Q3	Q4	Total
2000	$ 10.00	$ 20.00	$ 30.00	$ 40.00	$ 100.00
2001	10.00	20.00	30.00	40.00	100.00
2002	10.00	20.00	30.00	40.00	100.00
2003	10.00	20.00	30.00	40.00	100

...it's a *representation* of a spreadsheet

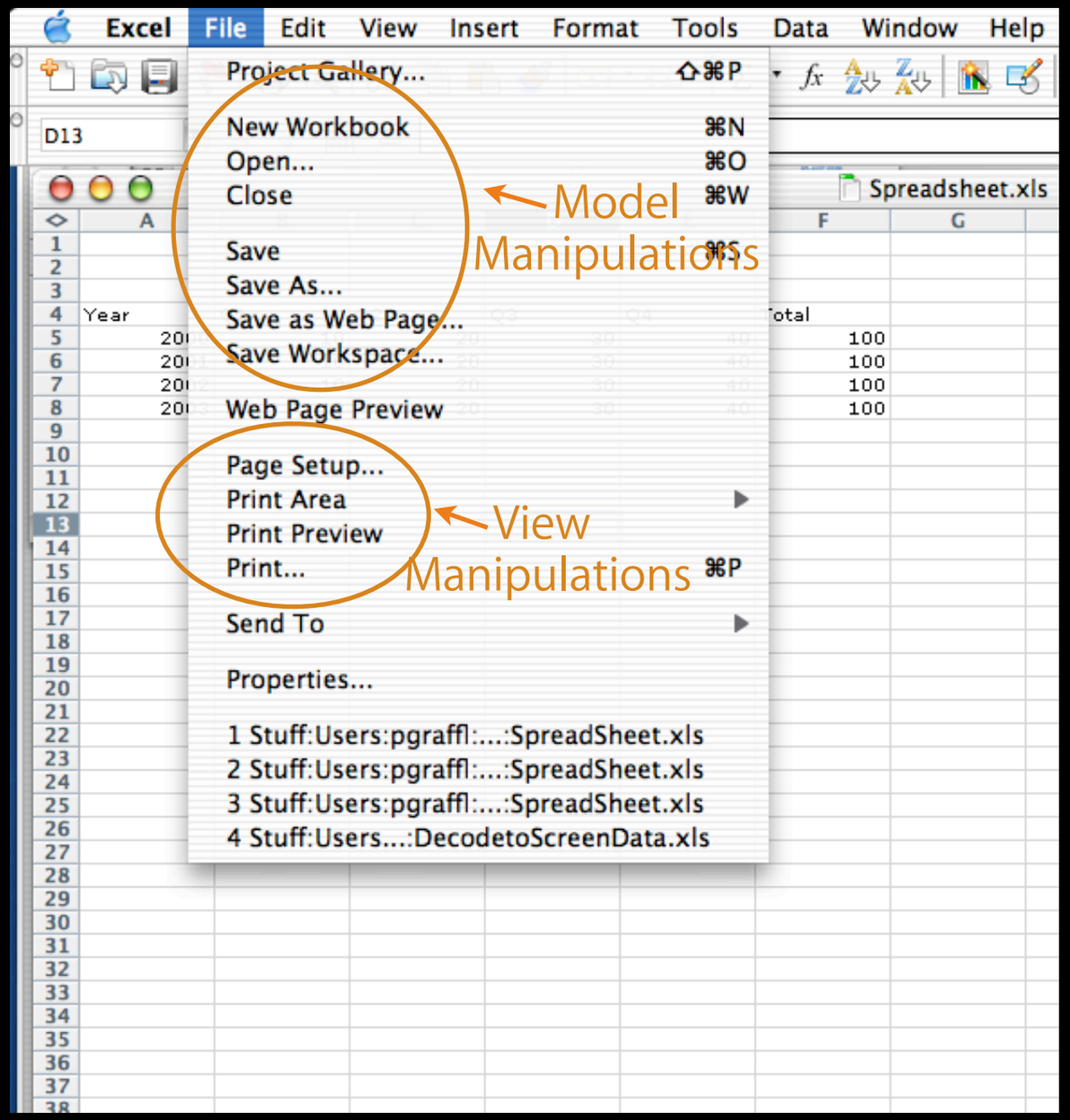
Model vs. View





- Hi-fidelity model representation
- Requires Application
- Configuration dependent
  - Fonts, plugins, app version

- Hi-fidelity view representation
- Does not require Application
- Configuration independent



Why Is "Save As PDF…" in the Print Panel?

- PDF is not a model level concept
- "Saving to PDF" is really just "Printing to Digital Paper"
- Mac OS X is the first commercial OS to have a system-wide standard for Digital Paper

PDF Is Not a Model Level Construct…

- Consider encoding editable, flowable text in PDF
- Imposes a model on a view level construct
- Text flow models are complicated
- A precise specification includes:
  - Styling model
  - Obstacle avoidance model
  - Pagination model (widows and orphans)
  - Justification model
  - Hyphenation model (requires language dictionary)

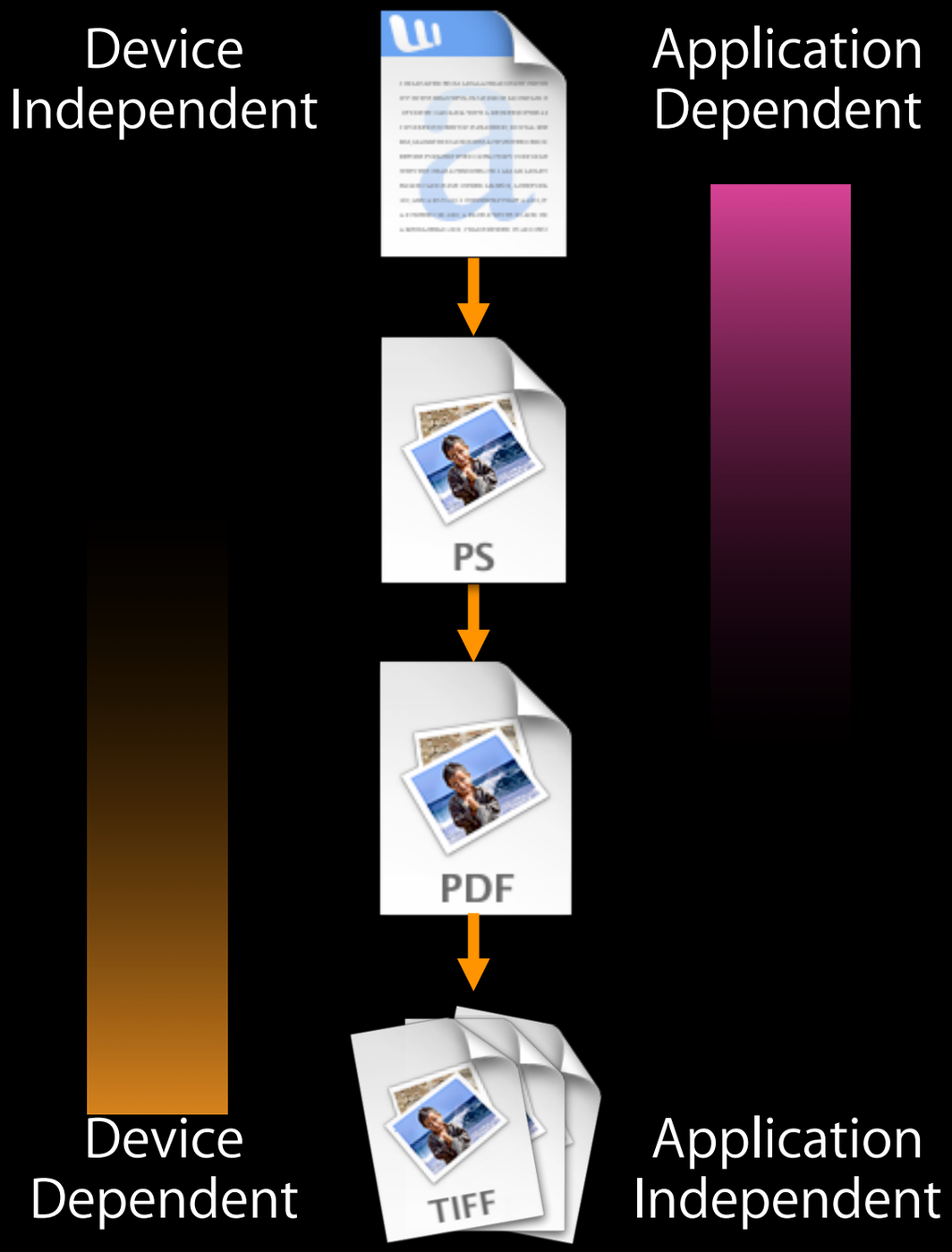
PDF Is Not a Good Fit for Carrying Model-level Data

- Sacrifices universality
  - PDF is a universal abstraction for marks on a page
  - There isn't a single universal abstraction for "flowable text documents", or "spreadsheets", nor should there be
- Models are precisely where applications innovate and differentiate
- We want apps to innovate and differentiate

Our Strategy

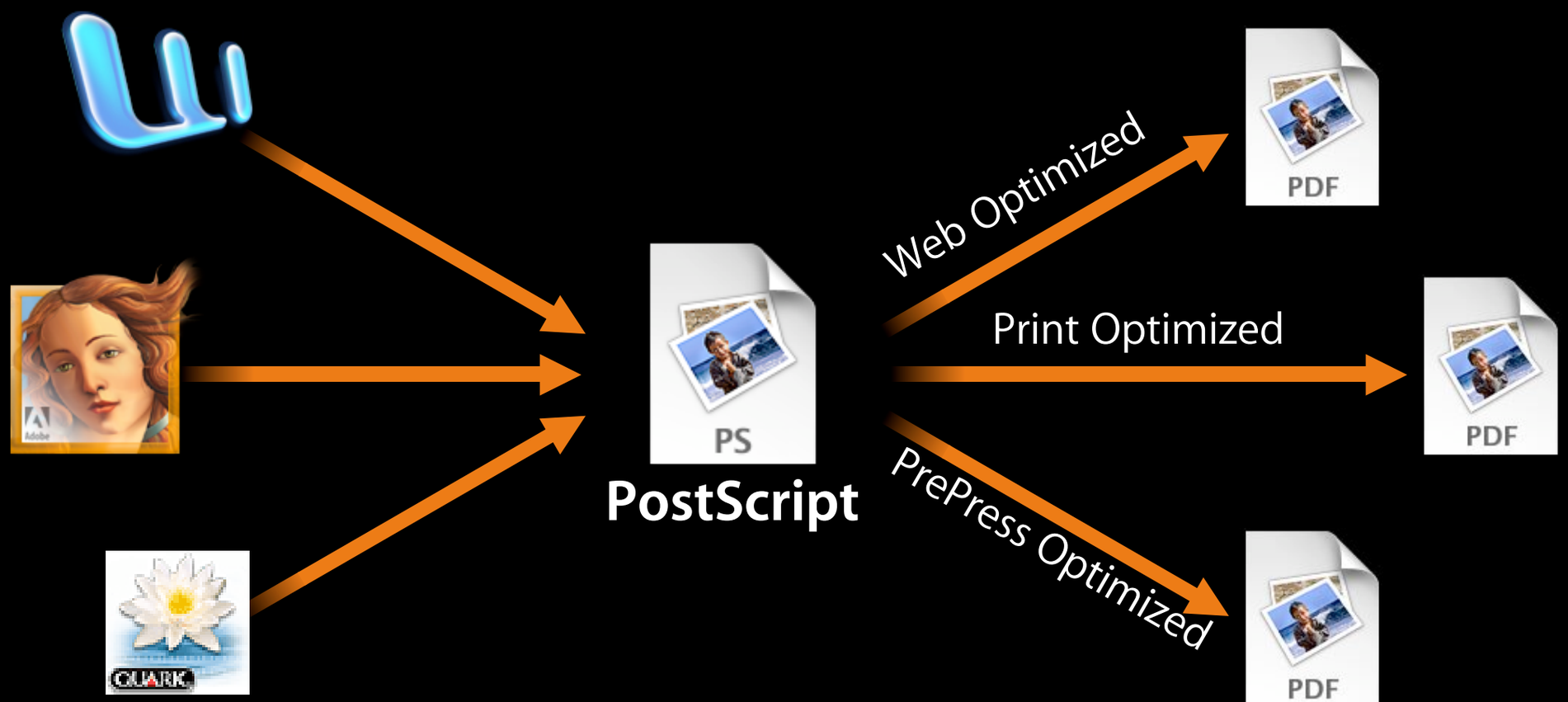
- Use PDF as Digital Paper:
  - Final form, paginated documents and vector artwork
- Use other formats, such as XML to encode models
  - Keynote file-format, others…
- Build a rich OS framework for Digital Paper
- Encourage Applications to differentiate by developing innovative models
- Long live MVC separation :-)

Graphic Arts Workflow



- Start with Application-dependent models
- Convert to application independent, device-independent marks on page
- Manipulate pages
- Convert to device-dependent representations

Traditional PS/PDF Workflow

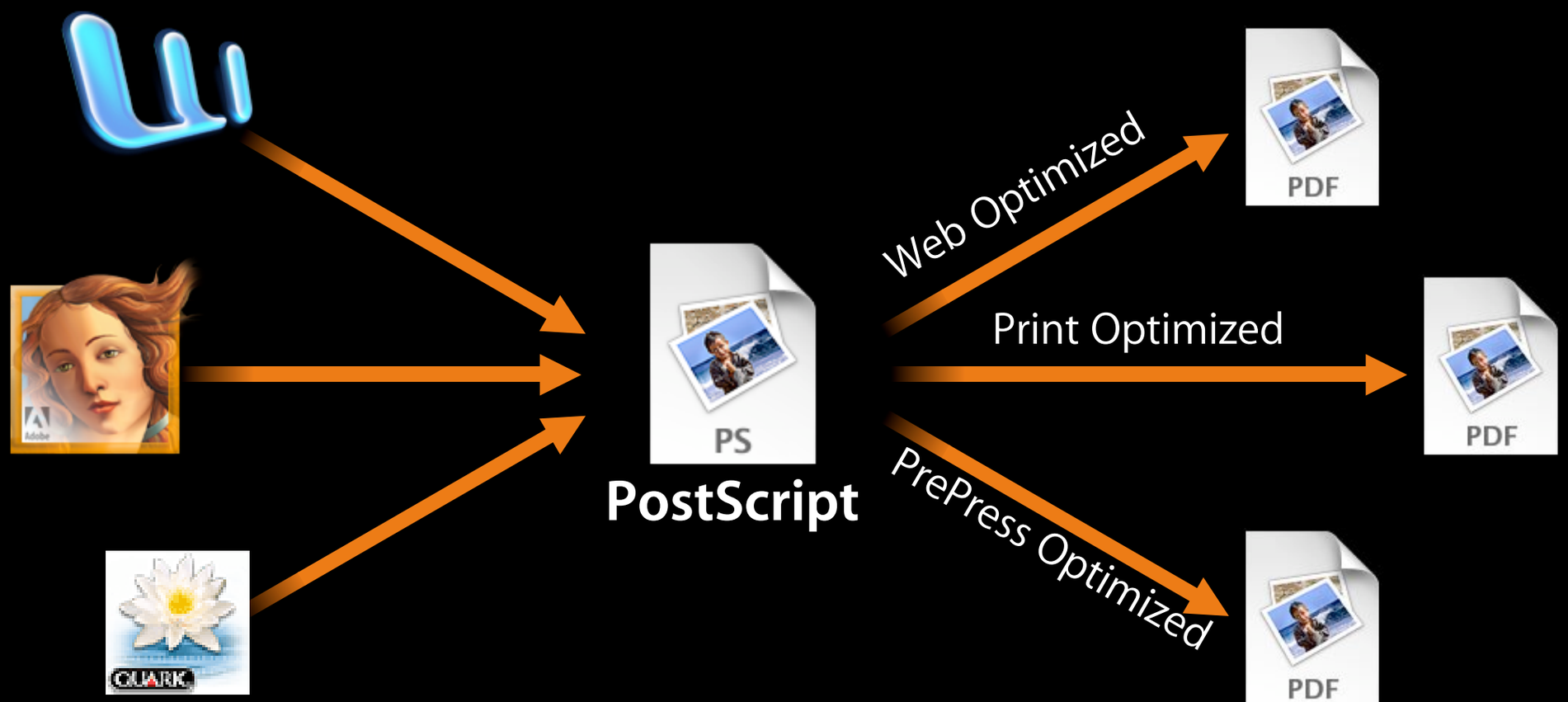


… But Wait

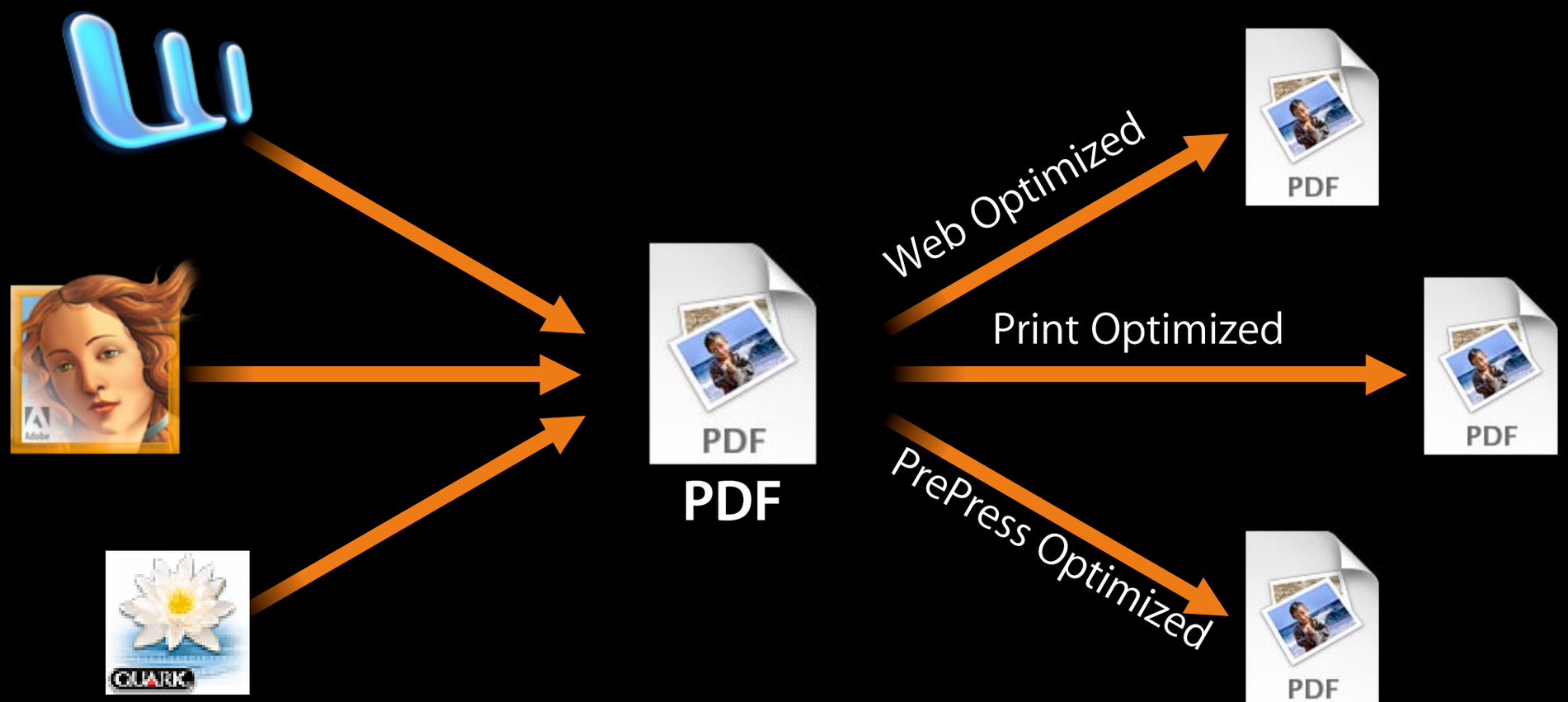
- Isn’t PDF device independent?
- What’s this “for Web” vs. “for Print” stuff?
- Suppose I create a “Web optimized” PDF and realize later that I need a “Print optimized” version?
- Do I keep the PS file around?
- Do we really want the PS file to be the application independent digital master?

NO!

Traditional PS/PDF Workflow

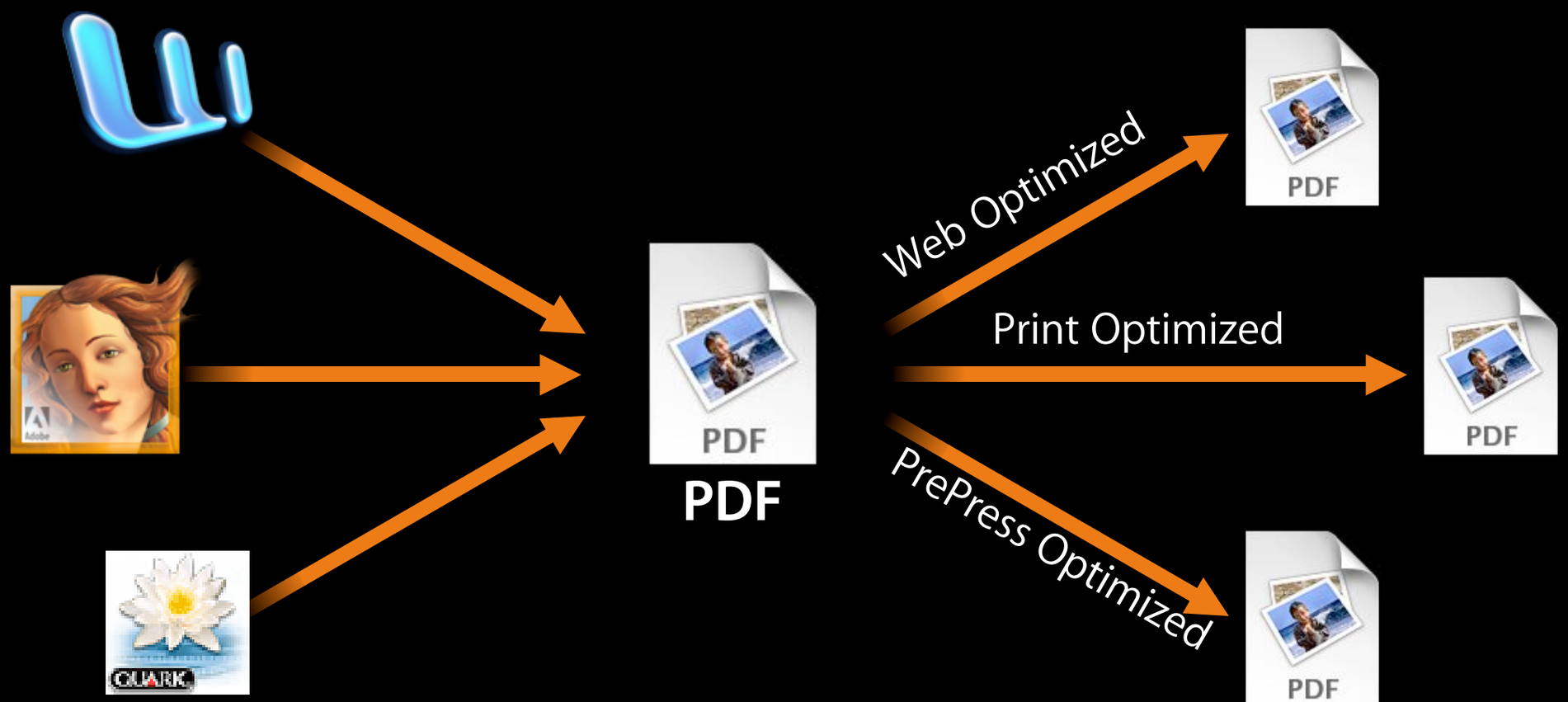


A Better Approach

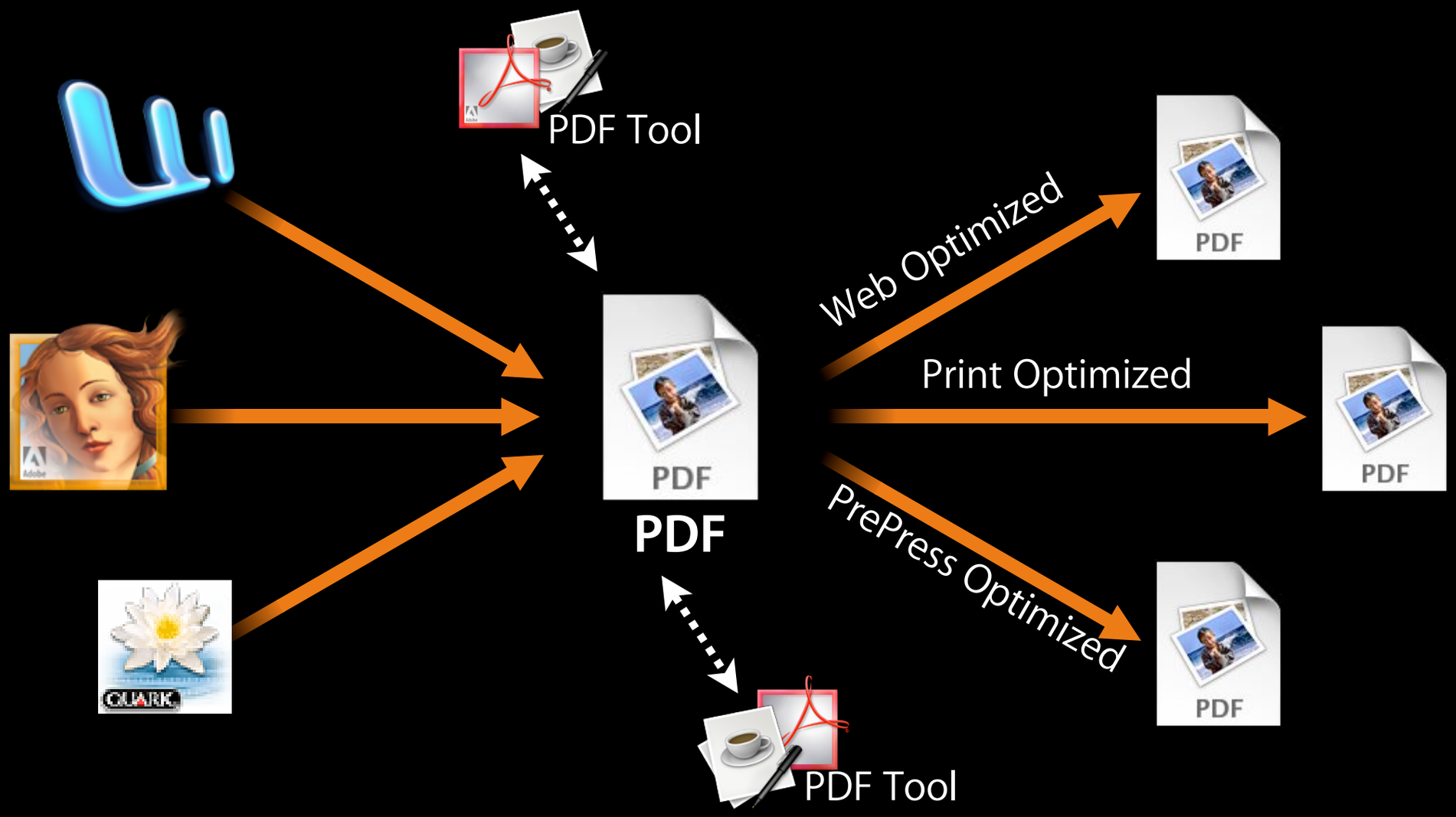


PDF Digital Paper

- Better suited “Digital Master” format than PostScript
- Viewable on 500M copies of Acrobat
- Lossless encoding of application intent
- “Digital Master” PDF does not pass judgement on application’s choice of:
  - Colorspace
  - Font technology
  - Image compression
  - Resolution


PDF
Web Optimized
PDF
Print Optimized
PDF
PDF
PrePress Optimized
PDF

Device-independent PDF Tools



PDF Processing on Mac OS X

- Version Tracker lists over 50 PDF applications on Mac OS X
- Panther will bring new opportunities

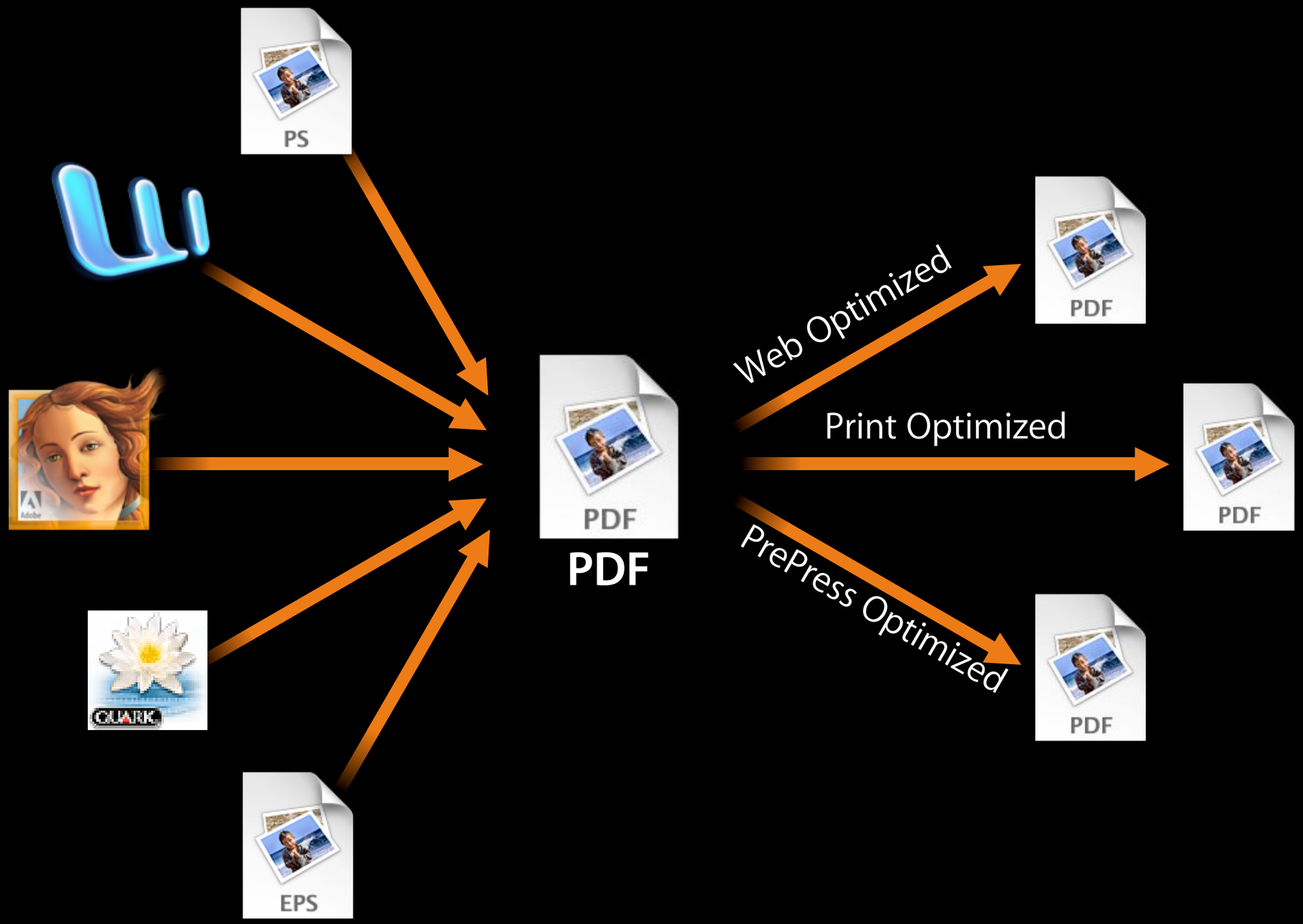
New PDF Workflow Toolset in Panther

- PostScript file handling
- User level scripting
- Quartz PDF filters
- Printing to a PDF workflow
- PDF Introspection APIs

PostScript to PDF Converter

- Gracefully deals with PS legacy files
- Provides “graphically lossless” transformation from PostScript to PDF
- Works for EPS as well
- Based on PostScript technology from Adobe
- Not a replacement for Distiller…
- Enables all printers to accept PostScript

PostScript Can Feed the Hub…



User-level Programmability

- Another lost aspect of PostScript legacy
- PostScript programming was useful for dynamically generating graphics
- PS program would “calculate” picture rather than “record” application drawing
- PDF can’t do this…
- … but reverse-polish notation was a real bear!

User-level Programmability

- Some folks found this aspect of PostScript useful…

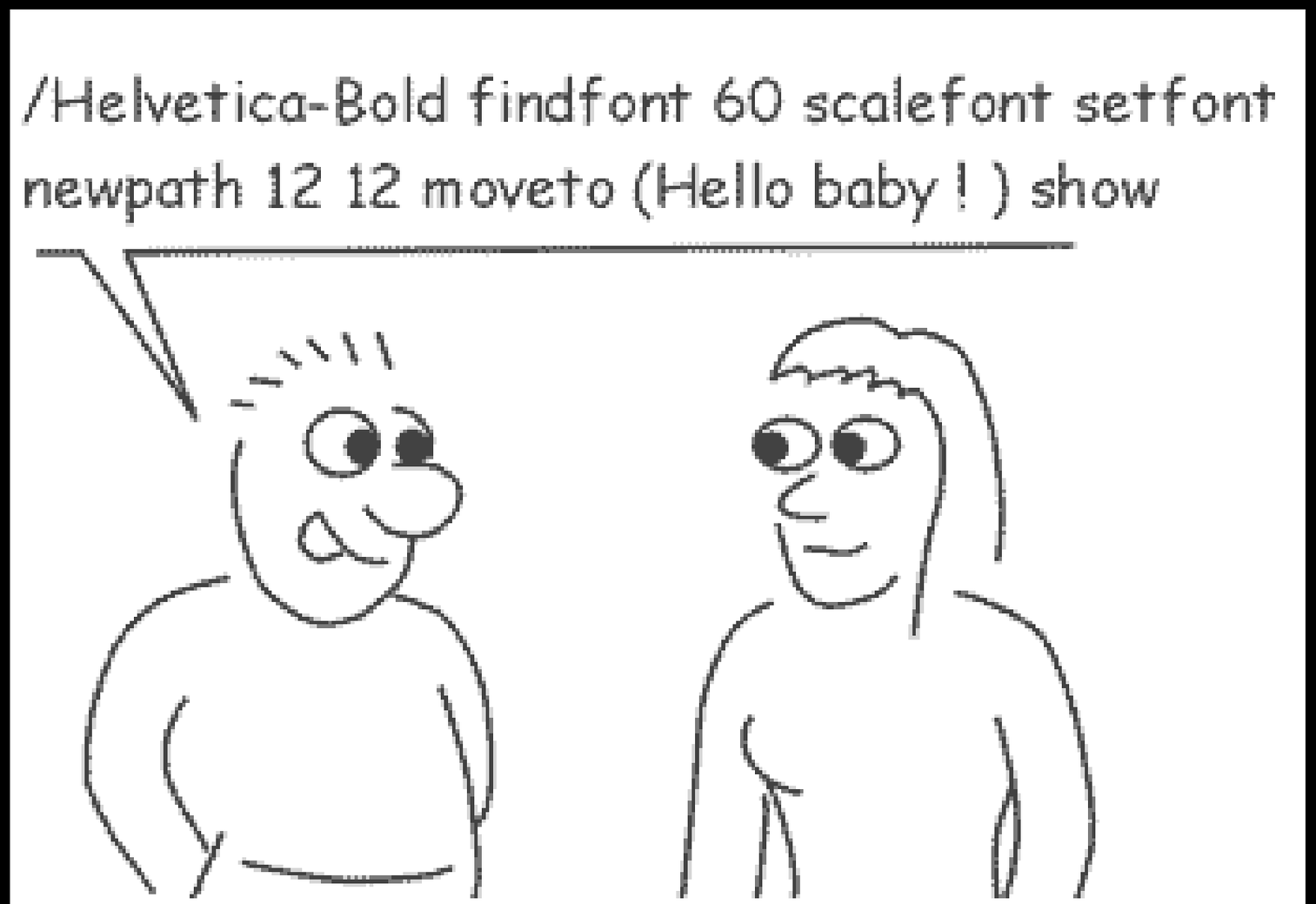


Image courtesy Laurens Leurs, http://www.prepressure.com

Quartz Scripting: Python Bindings for Quartz

- Full bindings for Quartz 2D API in Python
  - Allows PDF processing from scripts
- Convenience functions for:
  - Create CGImageRefs from files (via Quicktime Importer)
  - Save CGBitmapContext to files (via Quicktime Exporter)
  - Load HTML, RTF and Unicode Text (via Cocoa NSText)
  - Convert EPS and PS to PDF (via PS to PDF)
- Allows new generation of script writers to write simple tools

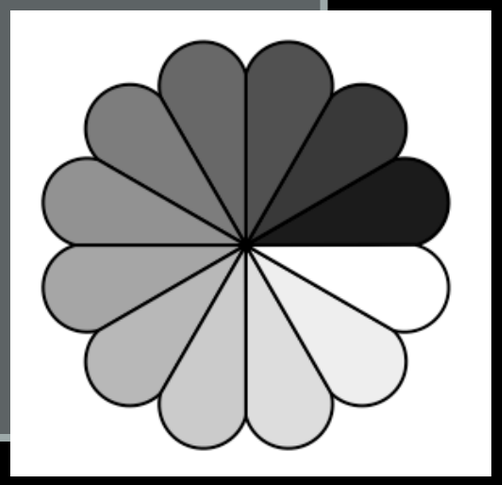
Quartz Scripting

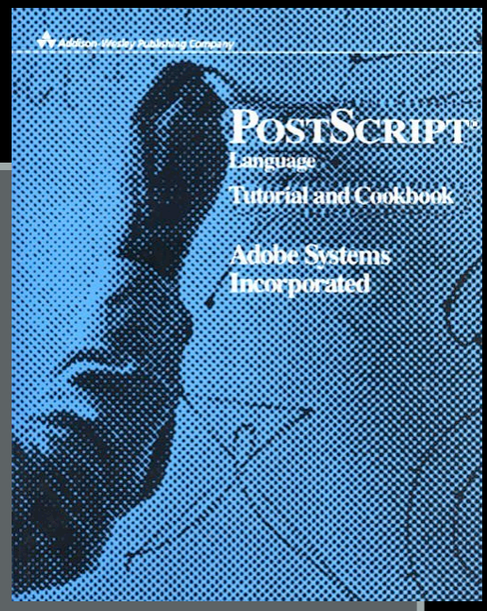
- Handy for small “one-off” processing scripts
- Rasterize PDF, HTML, RTF, PS documents into a bitmap and export via QuickTime
- Advanced imposition and page-to-paper mappings
- PDF concatenation
- Add a cover page, watermarks to a PDF
- Dynamic graphics generation on a server
- …unlike PS, can’t override marking operators
  - We consider this a feature :-)

Example

- PostScript Cookbook Wedge example

```
#!/usr/bin/python
from CoreGraphics import *
import math

#  For old times sake -- the PostScript cookbook wedge example
in python...

def inch(x):
	return 72*x

def rad(angle):
	return angle*math.pi/180.0

def wedge(c):
	c.beginPath()
	c.moveToPoint(0,0)
	c.translateCTM(1,0)
	c.rotateCTM(rad(16))
	c.translateCTM(0, math.sin(rad(15)))
	c.addArc(0,0, math.sin(rad(15)), rad(-90), rad(90), 0)
	c.closePath()

pageRect = CGRectMake (0, 0, 612, 792)   #  landscape
c = CGPDFContextCreateWithFilename ("wedge.pdf", pageRect)
c.beginPage(pageRect)
c.saveGState()
c.translateCTM(inch(4.25), inch(4.25))
c.scaleCTM(inch(1.75), inch(1.75))
c.setLineWidth(.02)
for i in range(1,13):
	c.setGrayFillColor(i/12.0,1.0)
	c.saveGState()
	wedge(c)
	c.fillPath()
	c.restoreGState()
	c.saveGState()
	c.setGrayStrokeColor(0,1)
	wedge(c)
	c.strokePath()
	c.restoreGState()
	c.rotateCTM(rad(30))
c.restoreGState()
c.endPage()
del(c)
```





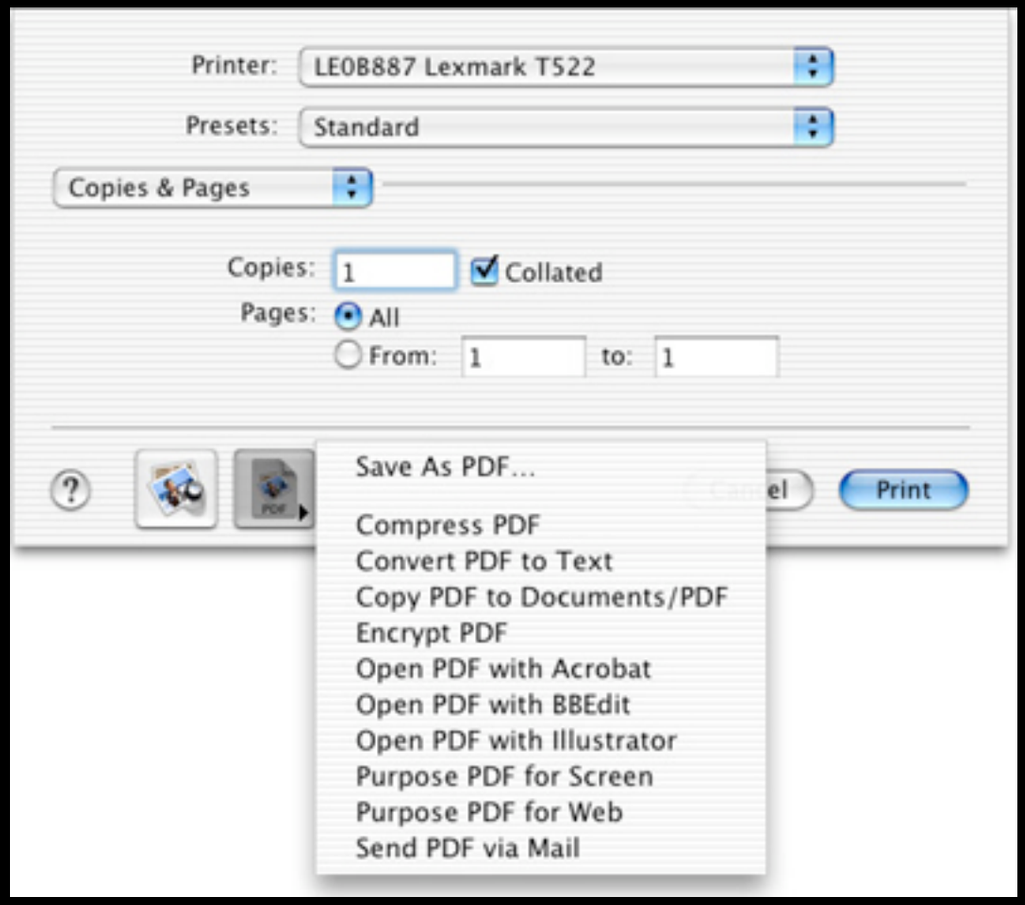

```
%!PS-Adobe-3.0
%%BoundingBox: 172 173 259 260

/inch {72 mul} def

/wedge
{ newpath
  0 0 moveto
  1 0 translate
  15 rotate
  0 15 sin translate
  0 0 15 sin -90 90 arc
  closepath
} def

gsave
  3 inch 3 inch translate
  0.5 inch 0.5 inch scale
  0.02 setlinewidth
  1 1 12
  { 12 div setgray
    gsave
      wedge
      gsave
       fill
      grestore
      0 setgray
      stroke
    grestore
    30 rotate
  } for

grestore

showpage
```

Quartz PDF Filters

- Allows processing of PDF transformations based on “recipes”
- “Recipes” are created in ColorSync Utility
- Can be used for color conversion or effects
- Image resampling and compression is also an option

Print-to-PDF Workflow

- Workflow items are placed here:
  - ~/Library/PDF Services, /Library/PDF Services
- Supported Workflow items
  - Folder
  - Folder alias
  - Application or application alias
  - CLI tool
  - AppleScript
  - Quartz Filter (new on Panther)



PDF Introspection APIs

- Complete access to PDF document structure
- Dictionaries, Strings, Arrays, Streams
- Does not model internals of GraphicsStreams
- Useful for extracting links, annotations, metadata, etc.

Demo

Preview and PDF Workflow

Quartz and PDF Summary

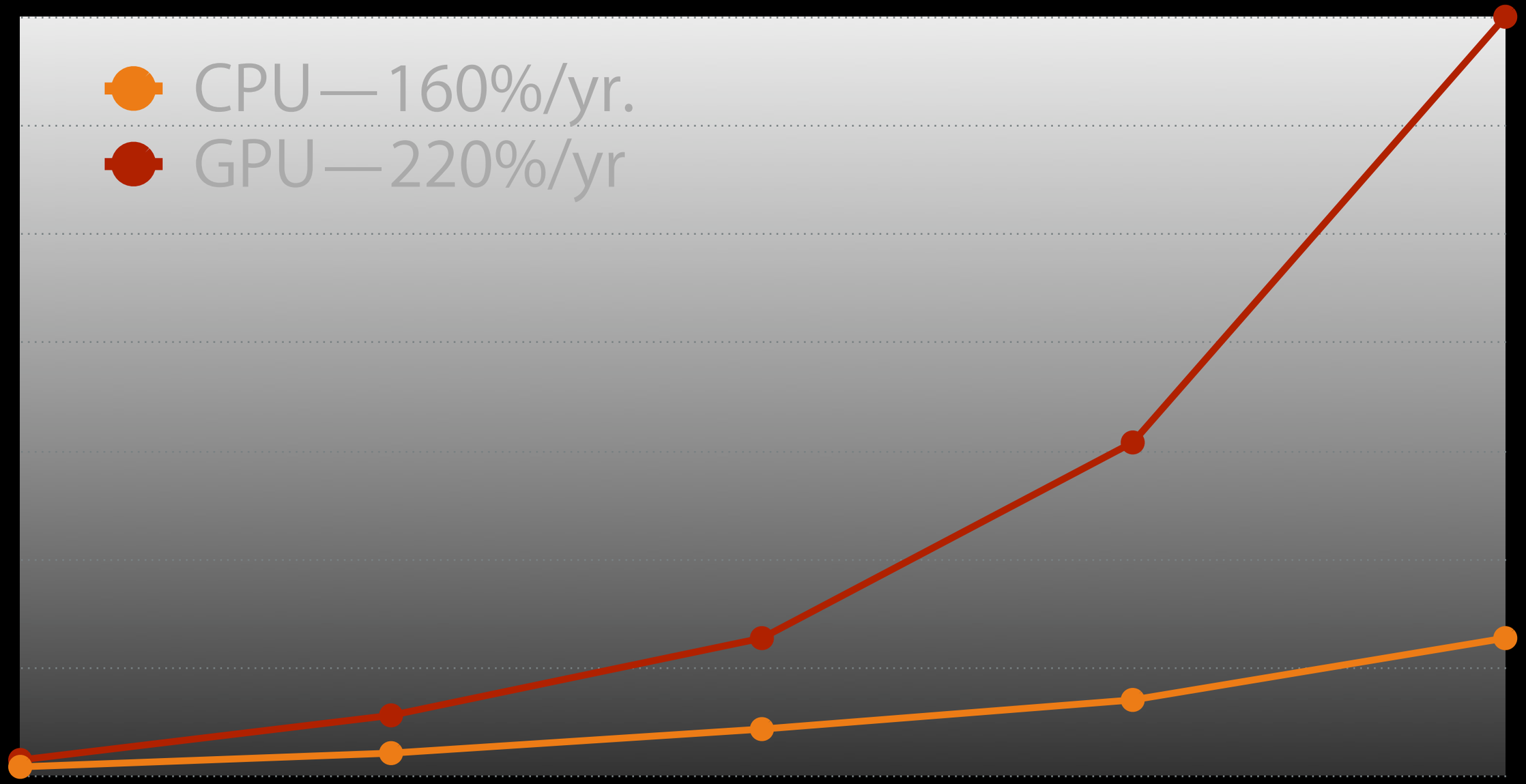
- PDF provides Mac OS X with a universal representation of “Digital Paper”
- Apple’s strategy is to continue to build upon the “view” level abstraction of PDF
- Panther adds significantly to the PDF toolset
- If you’re still thinking PixMaps and GWorlds, come join the Quartz 2D party!

The GPU Computing Revolution

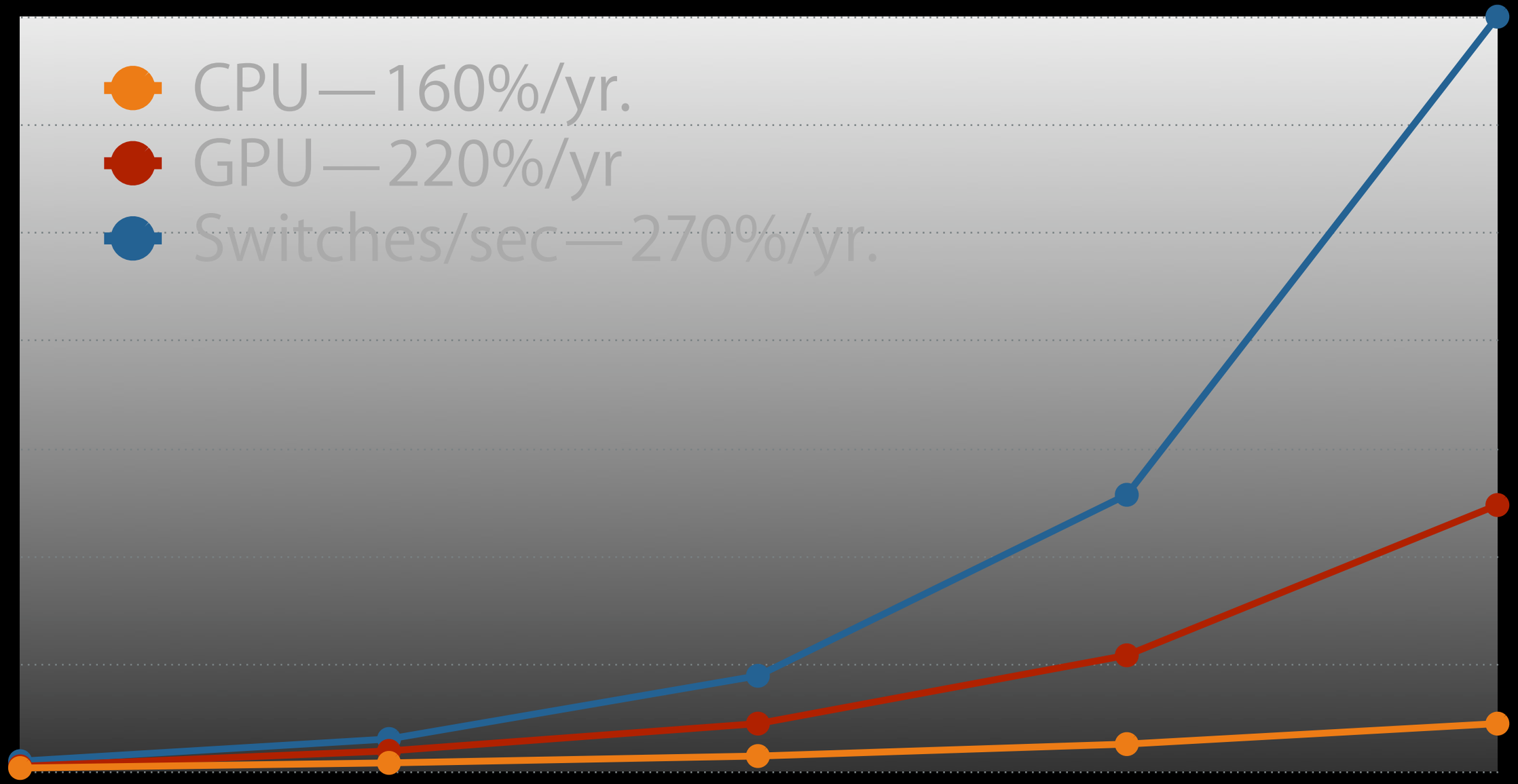
First Some Numbers…

- GPUs can composite images faster than CPUs
- GPU:
  - 8 pixels per clock @ 400 MHz
  - 21.8 GB/s memory bandwidth
- CPU:
  - ~1 pixel per clock @ 2 GHz
  - 6.4 GB/s memory bandwidth
- Frees CPU for application work

CPUs vs. GPU Performance



“Capability” Growth Even Higher…



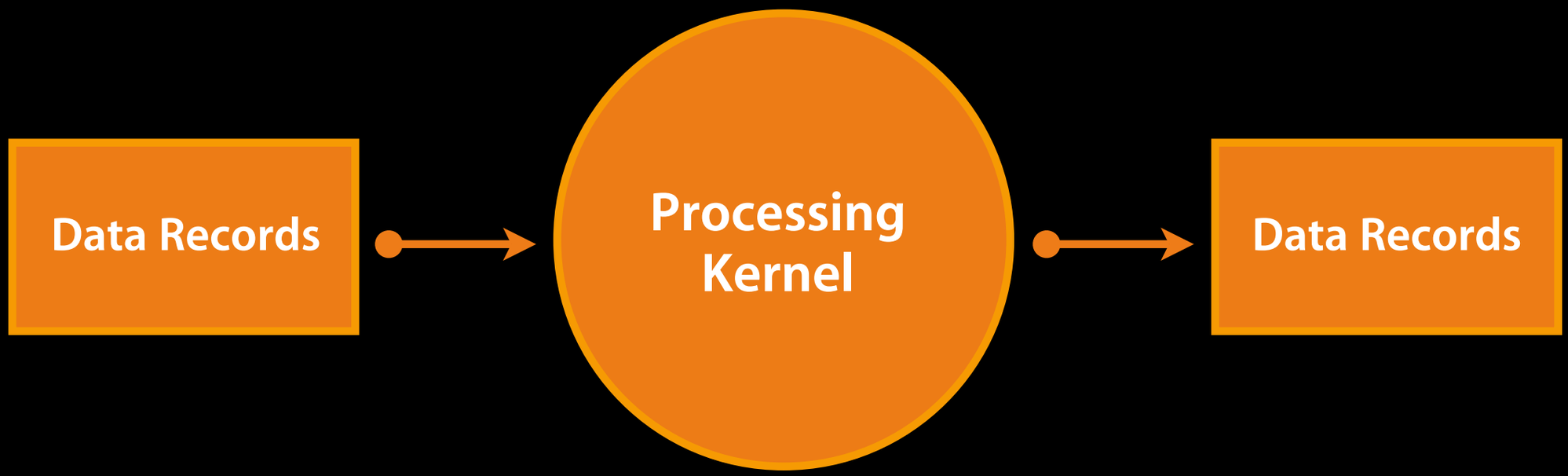
Why Is This So?

- What do GPU designers know that CPU designers don't?
  - Answer: Nothing!
- GPUs are not general purpose processors
  - Computation is "embarrassingly parallel"
- Entertainment applications (i.e., games) have provided a sustainable economic model for mass market parallel computing

Computational Intensity

- Arithmetic intensity / switch
  - GPU: double the gates => double the performance
  - CPU: double the gates => much less
- General-purpose CPUs dedicate a lot of resources to non-computational logic:
  - Instruction and data caches
  - Branch prediction
  - Instruction reordering
  - Data hazard avoidance

Stream Processing Model



Performance Benefits of Stream Processing

- A GPU can be thought of as 1000s of stream processors
- Get input from another stream processor
- Send output to next stream processor
- High-speed dedicated producer/consumer links
- Stream processors stays busy all the time
- Most stream units are dedicated logic…
- … programmability is emerging

The Graphics Pipeline

Primitive Submission

Vertex Processing

Triangle Rasterization

Fragment Processing

Blending, z-test, etc.

The Graphics Pipeline

Primitive Submission

- Convert Primitives into vertex stream
  - "Vertex" is a state bundle including:
    - Position vector
    - Normal vector
    - Color vector
    - Texture coordinate vectors
    - Actually up to 16 vector attributes

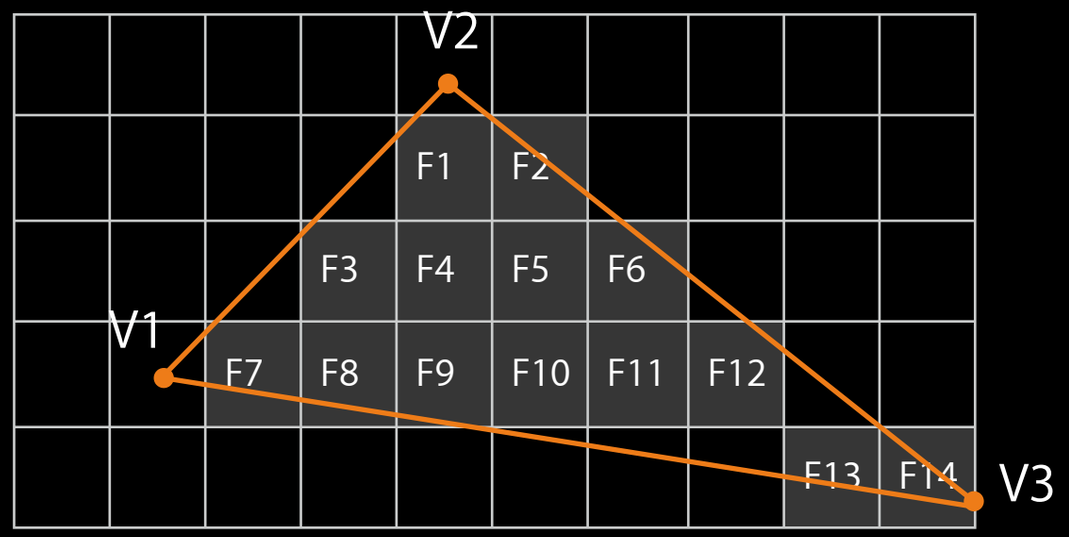
The Graphics Pipeline

Vertex Processing

- Vertices are processed
  - Spatial vectors transformed
  - Lighting calculated
  - Texture coordinates get generated and transformed

The Graphics Pipeline

Triangle Rasterization



Vertex Attributes interpolated over interior of triangle

The Graphics Pipeline

Fragment Processing

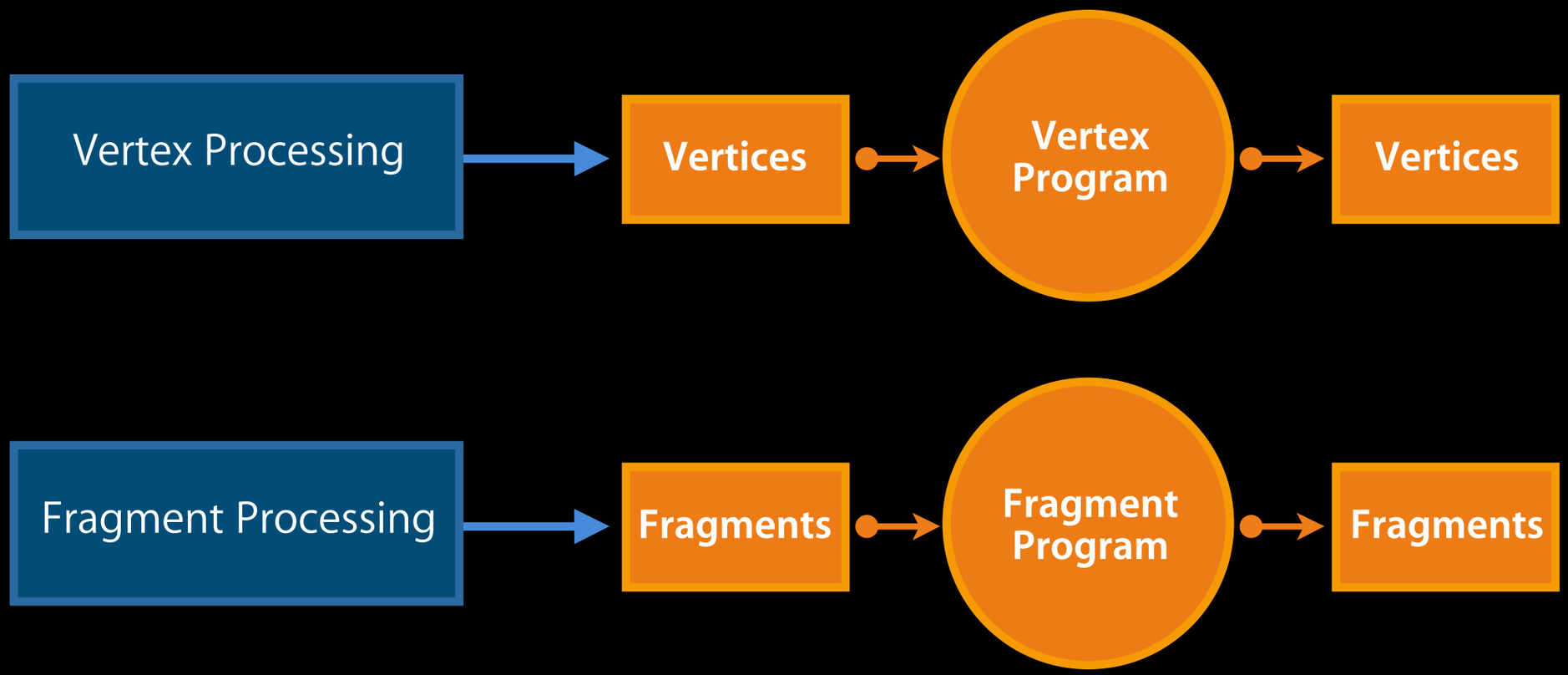
- Fragments are processed
  - Texture mapping applied
  - Final color and z calculated

The Graphics Pipeline

Blending, z-test, etc.

- Fragments are rendered
  - z-testing against framebuffer
  - Alpha-blending with framebuffer
  - Fog, etc.

The Programmable Graphics Pipeline



Pixel Programming on the GPU

- Data model similar to AltiVec
  - 128 bit 4-vectors of floats (e.g., RGBA, XYZW)
- Small program executed to calculate each output pixel
- Access to iterated vertex attributes
- Memory reads (texture lookups)
- Can’t read destination pixel
- Output left in special “result” register
- Powerful ALU and swizzling instructions

Pseudo Code for Pixel Program

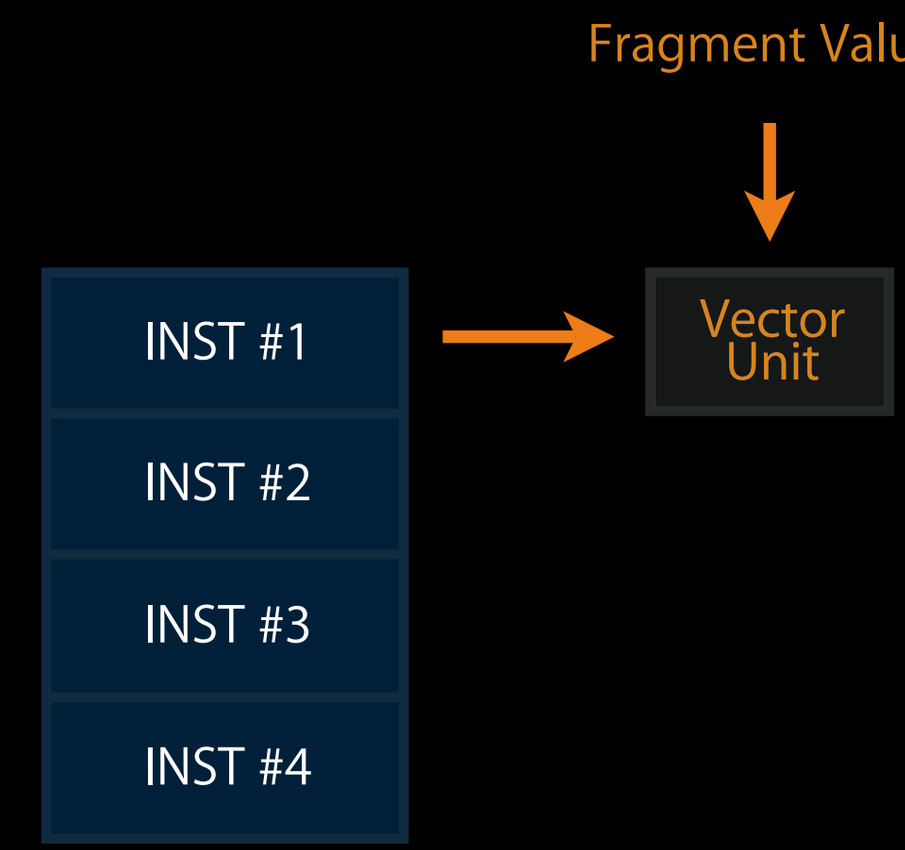
- All have the same basic function signature

```
global const vector globals[];  // vector constants
global vector textures[];       // pointers to textures

// return result based on interpolated values
vector  calculatePixel(const struct iteratedValues)
{
   vector result;
   result = iteratedValues.color;
   return result;
}
```

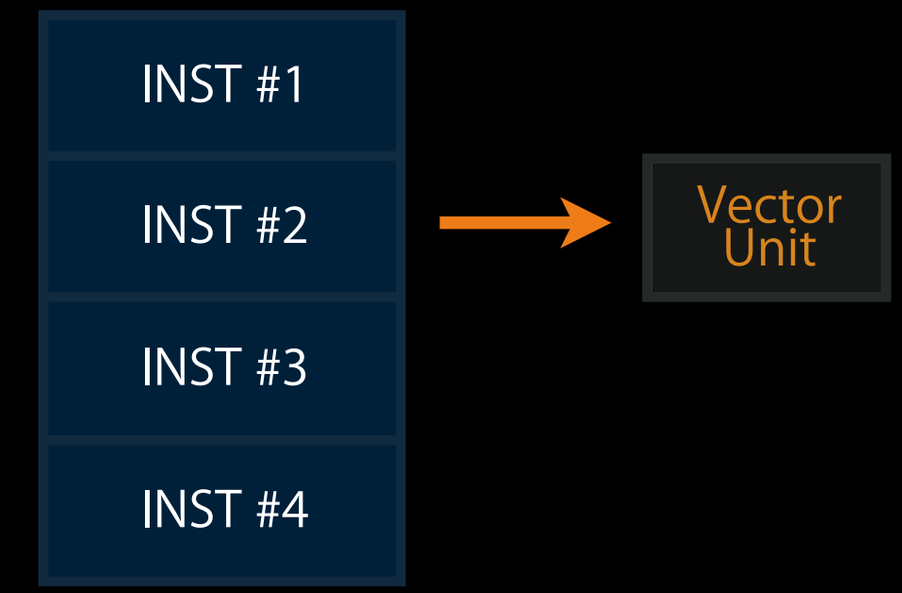
Disclaimer!

- Hardware design is hard
- The following examples are illustrative of the kinds of speed-ups possible with the constrained computational model

Sequential Processing



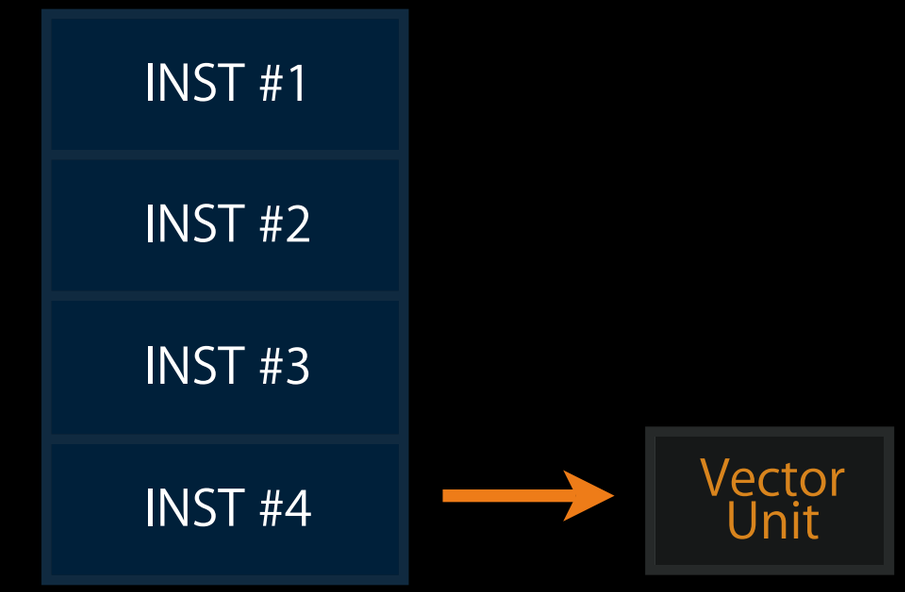
Sequential Processing



Sequential Processing

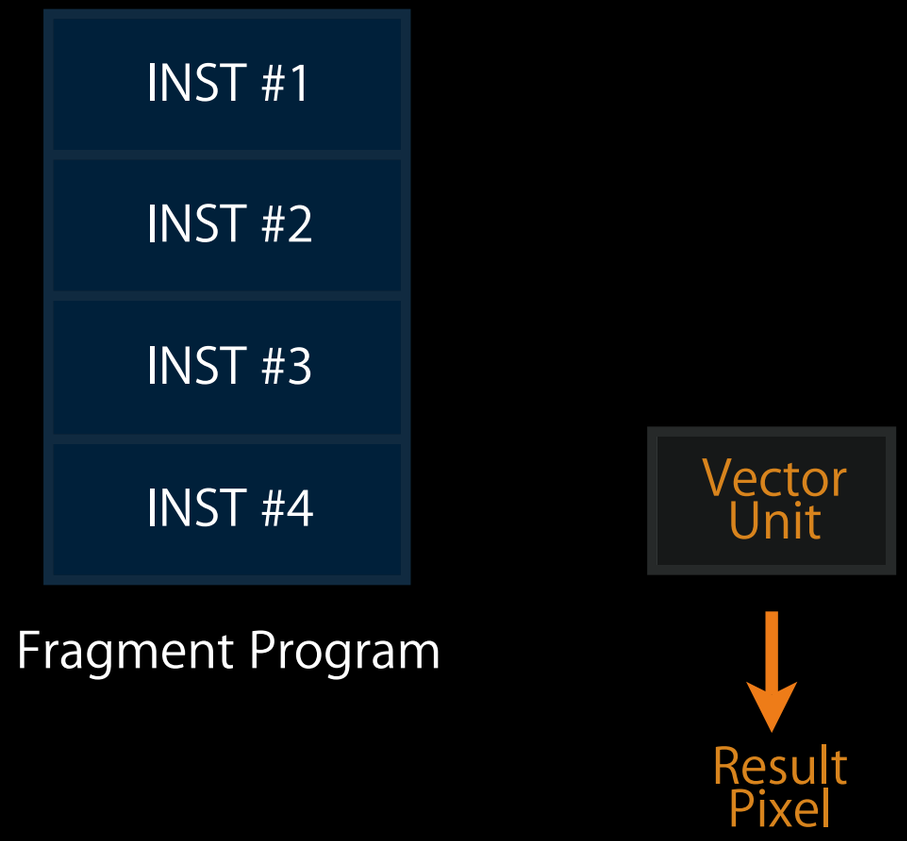
Fragment Program

Sequential Processing



Fragment Program

Sequential Processing



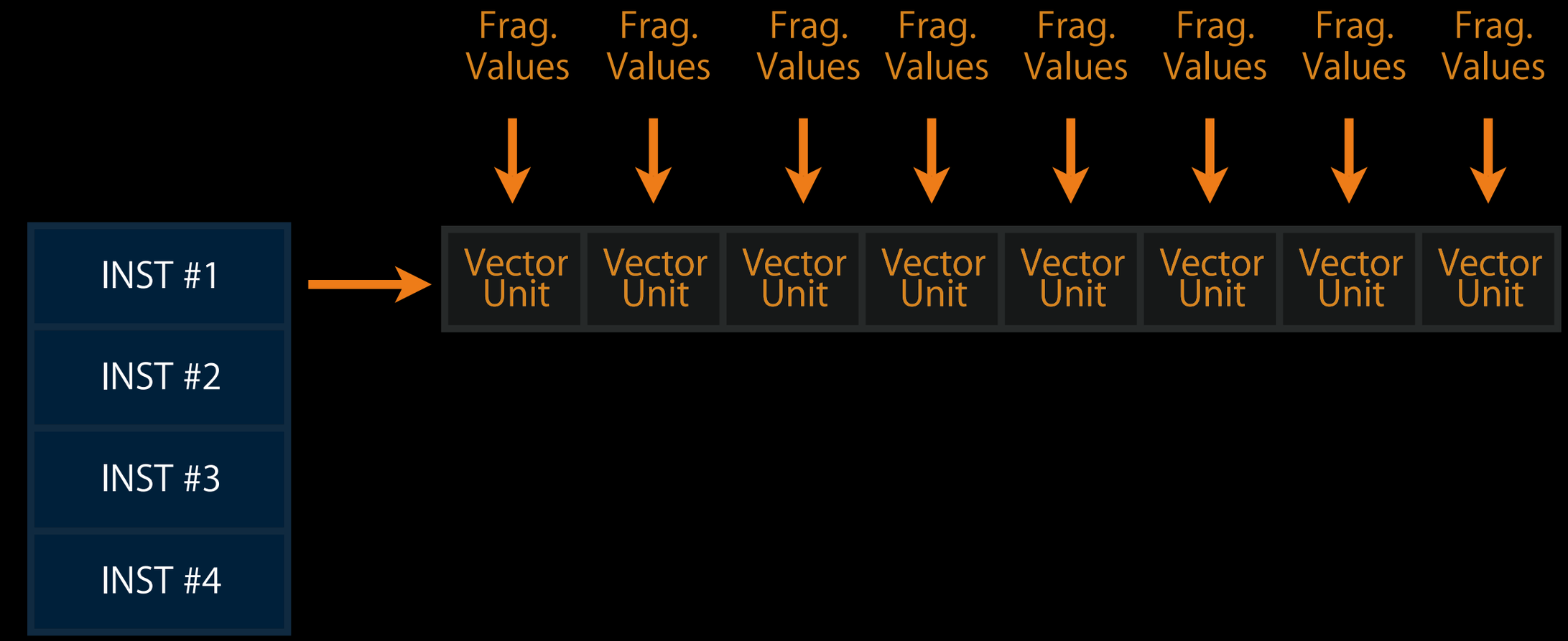
1 vector operation per clock
1 result every 4 clocks

Data Level Parallelism

- Pixel calculations are independent
- ResultPixel(i,j) cannot depend on ResultPixel(k,l)
- Pixel calculations can execute in parallel
- Call this parallelism in “space”
- Replicate the fragment execution unit and perform the same instruction on multiple pixels at once

Parallel Processing

Parallelism in “space” allows wide execution



Fragment Program

Parallel Processing

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Fragment Program

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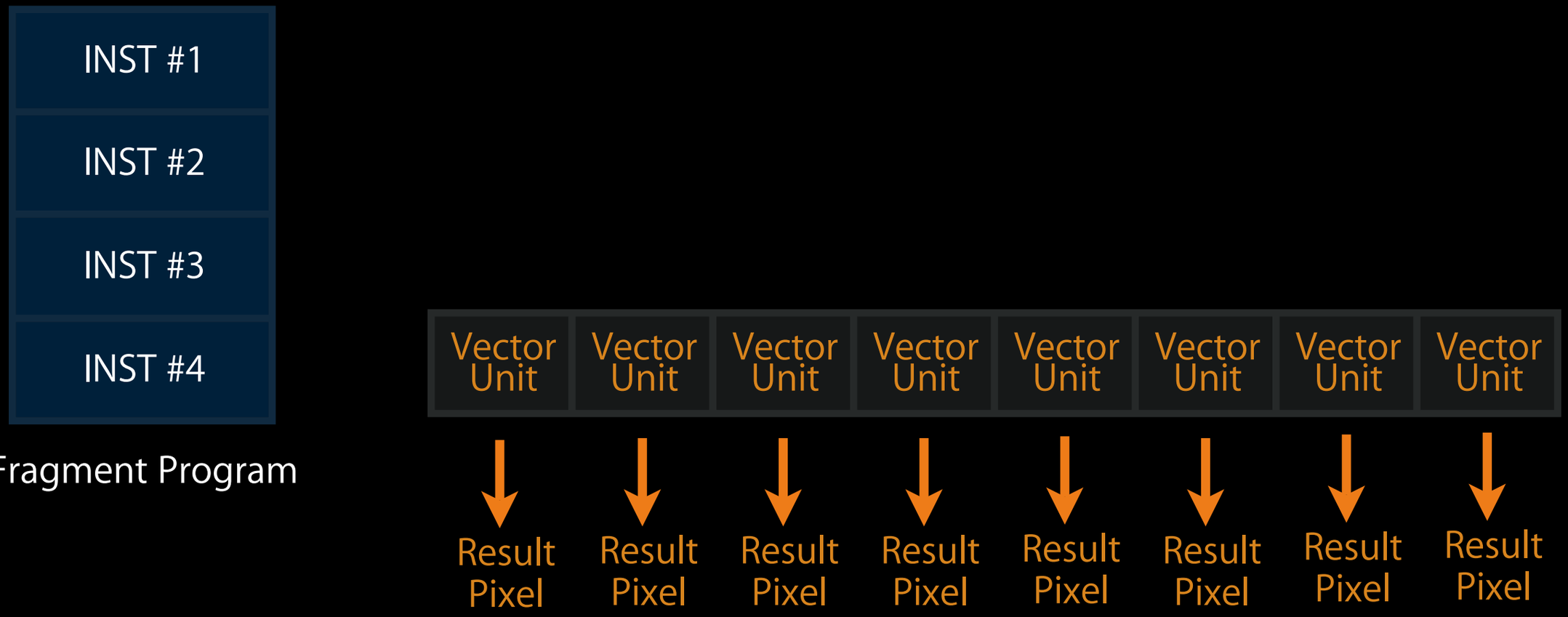


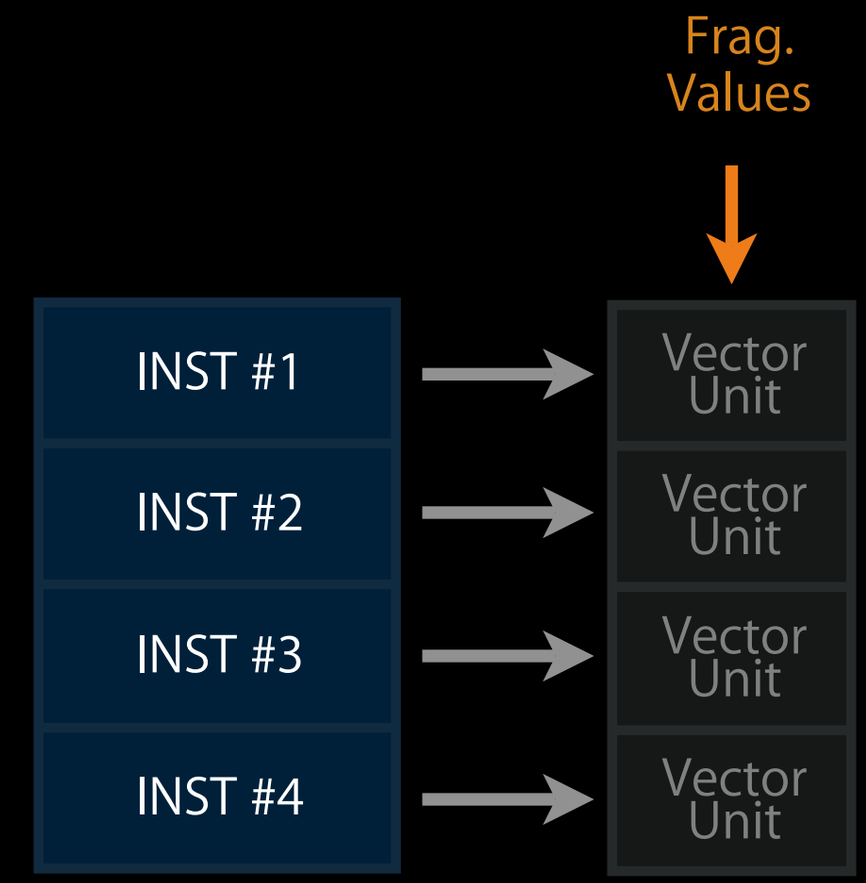
8 vector operations per clock
8 results every 4 clocks

Instruction Level Parallelism

- No writeable memory
- Machine state can only differ by one register from one instruction to the next
- Register renaming can hide instruction dependencies
- Code sequences are small and branchless
  - Static analysis at compilation time possible
- Physical registers > architecture registers

Parallel Processing

Parallelism in “time” allows pipelined execution



Fragment Program

Parallel Processing

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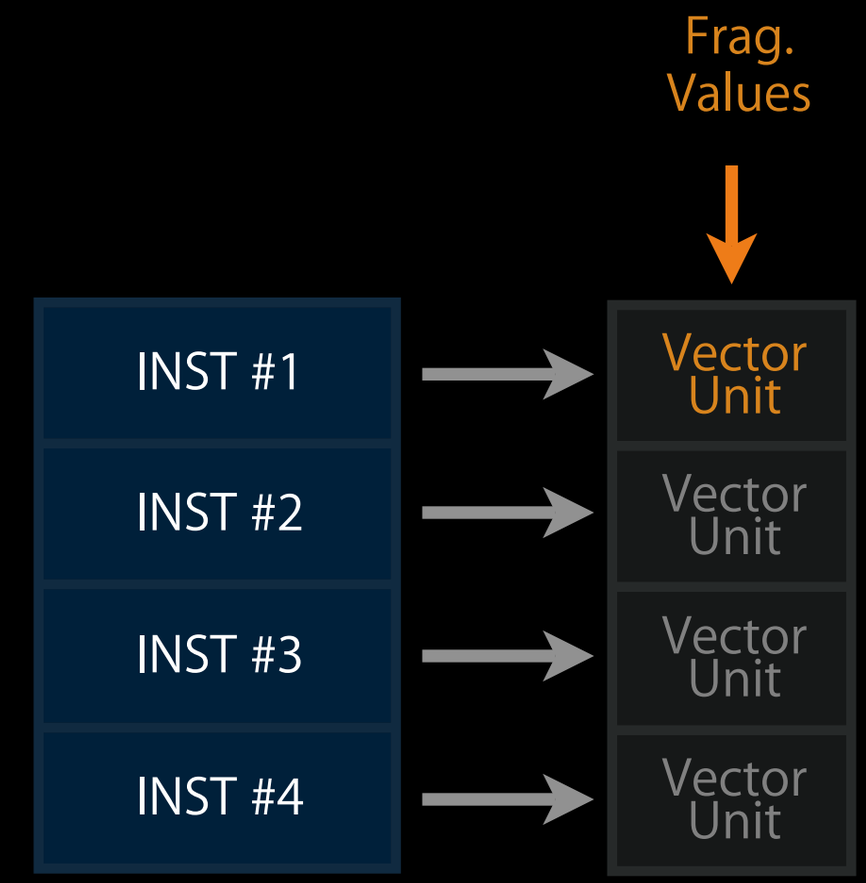

Fragment Program

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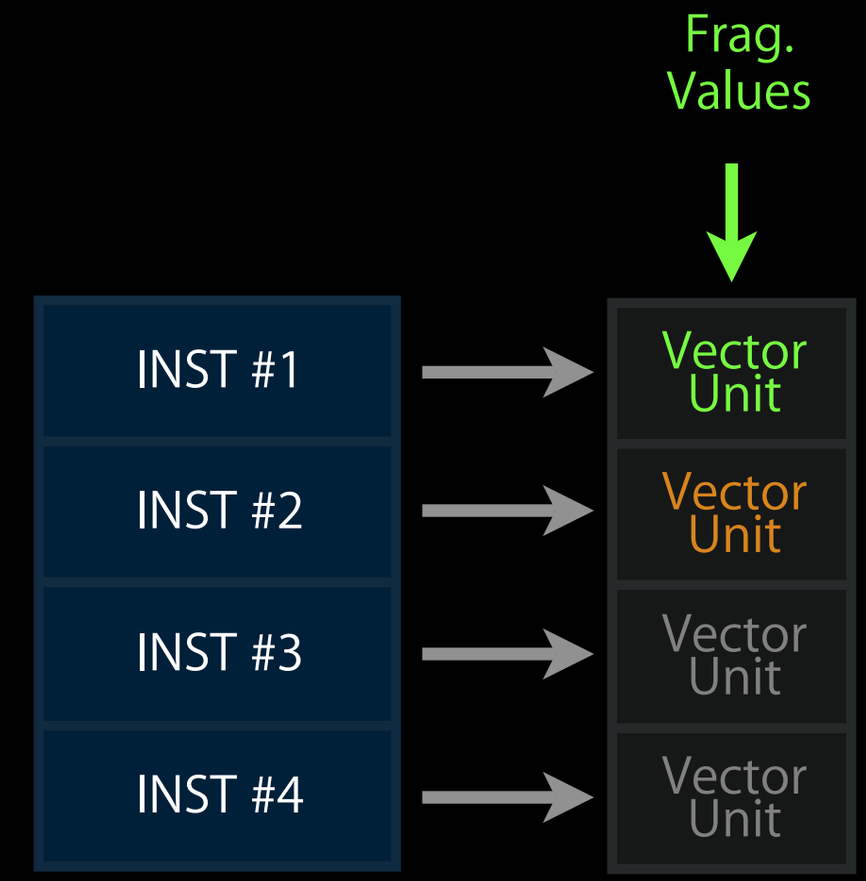

Fragment Program

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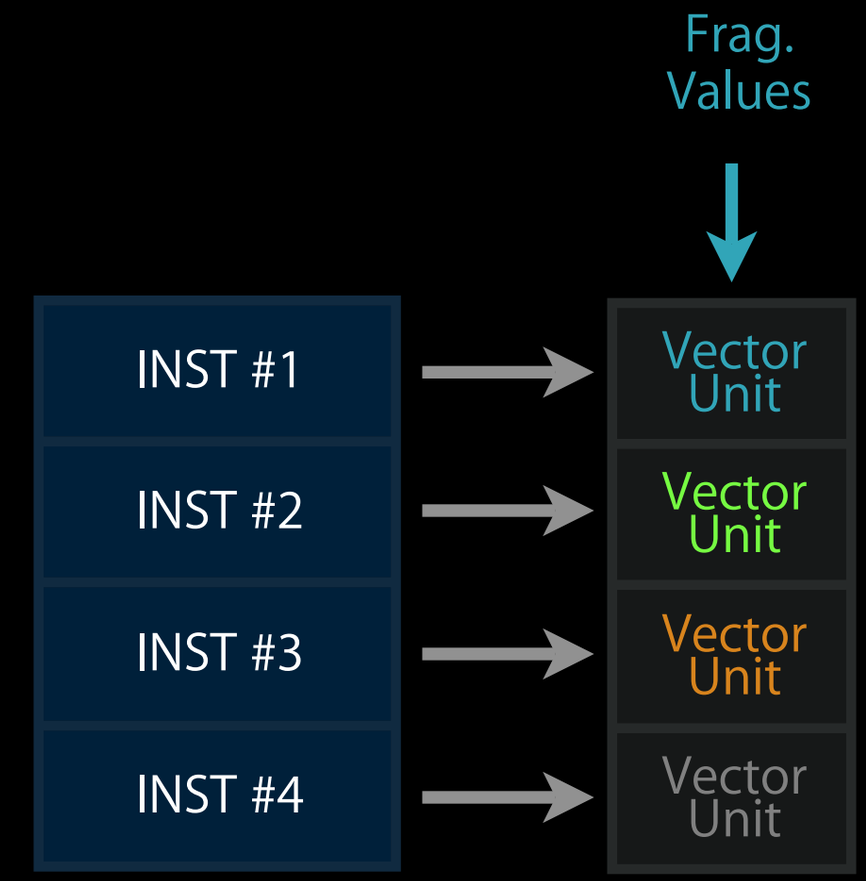

Fragment Program

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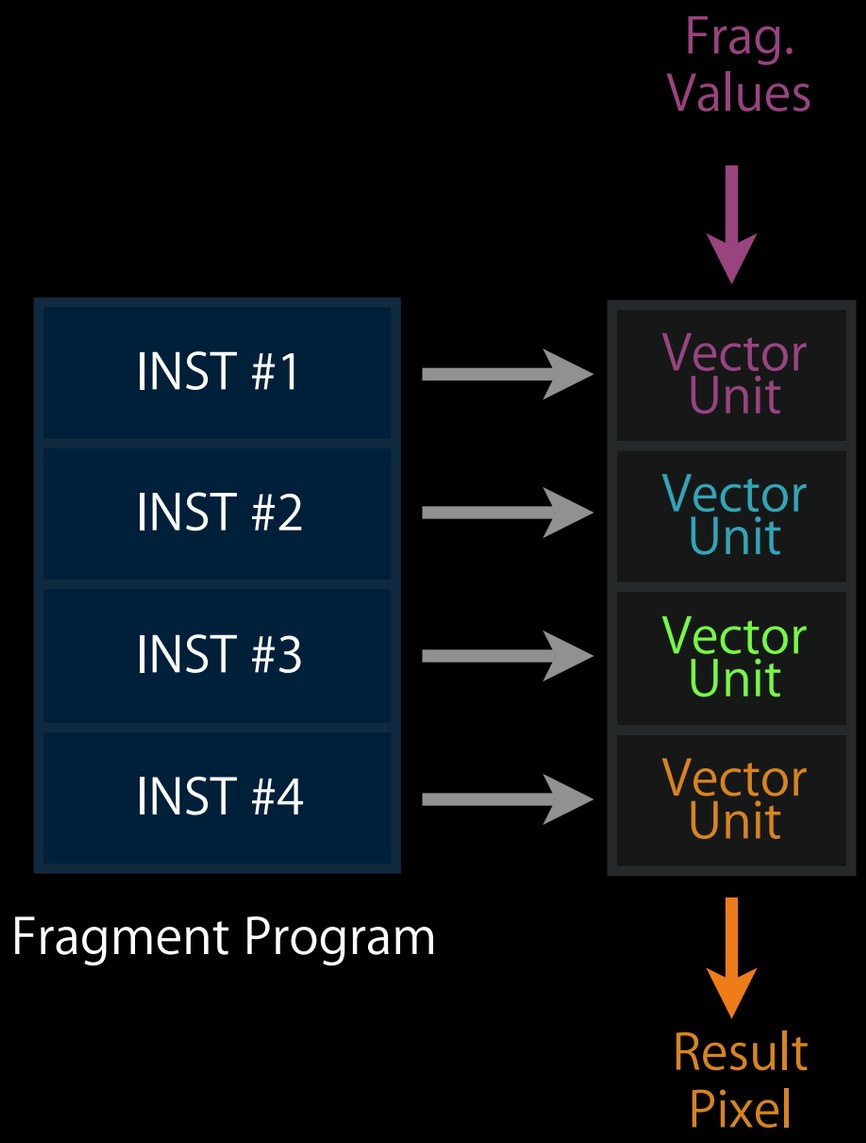

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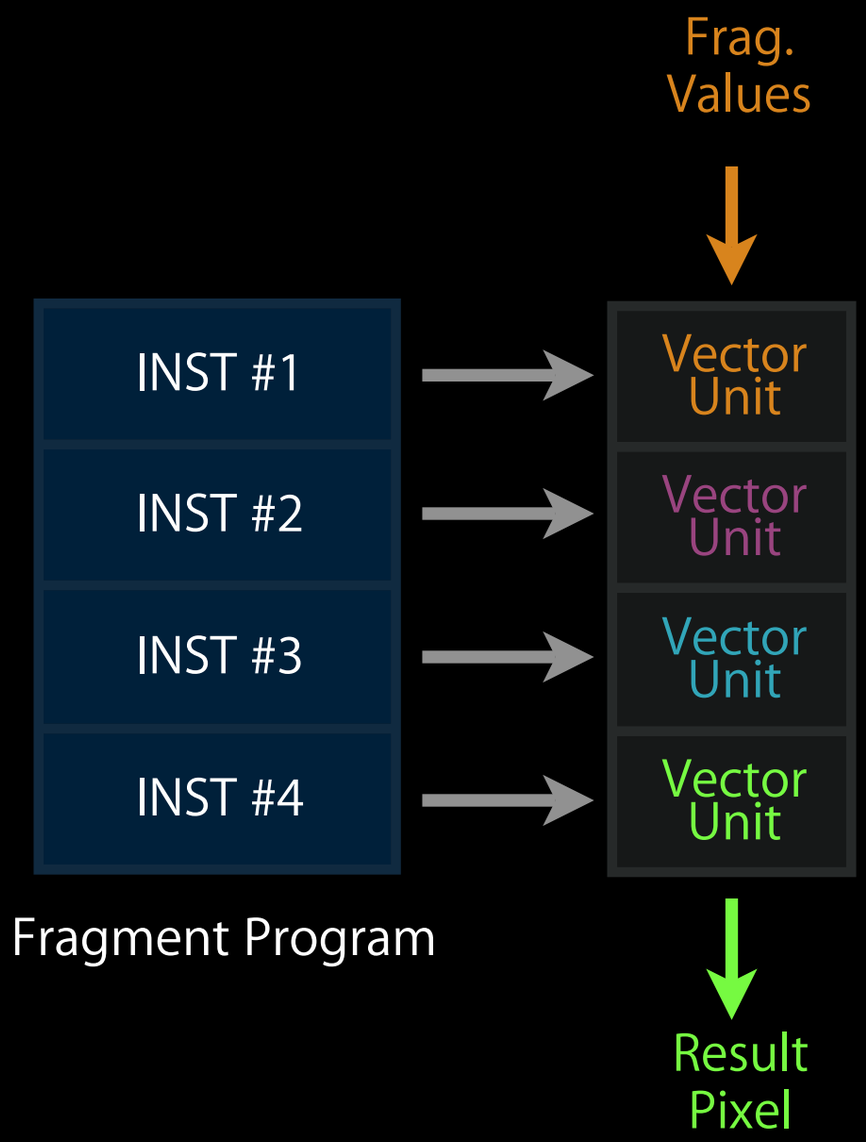

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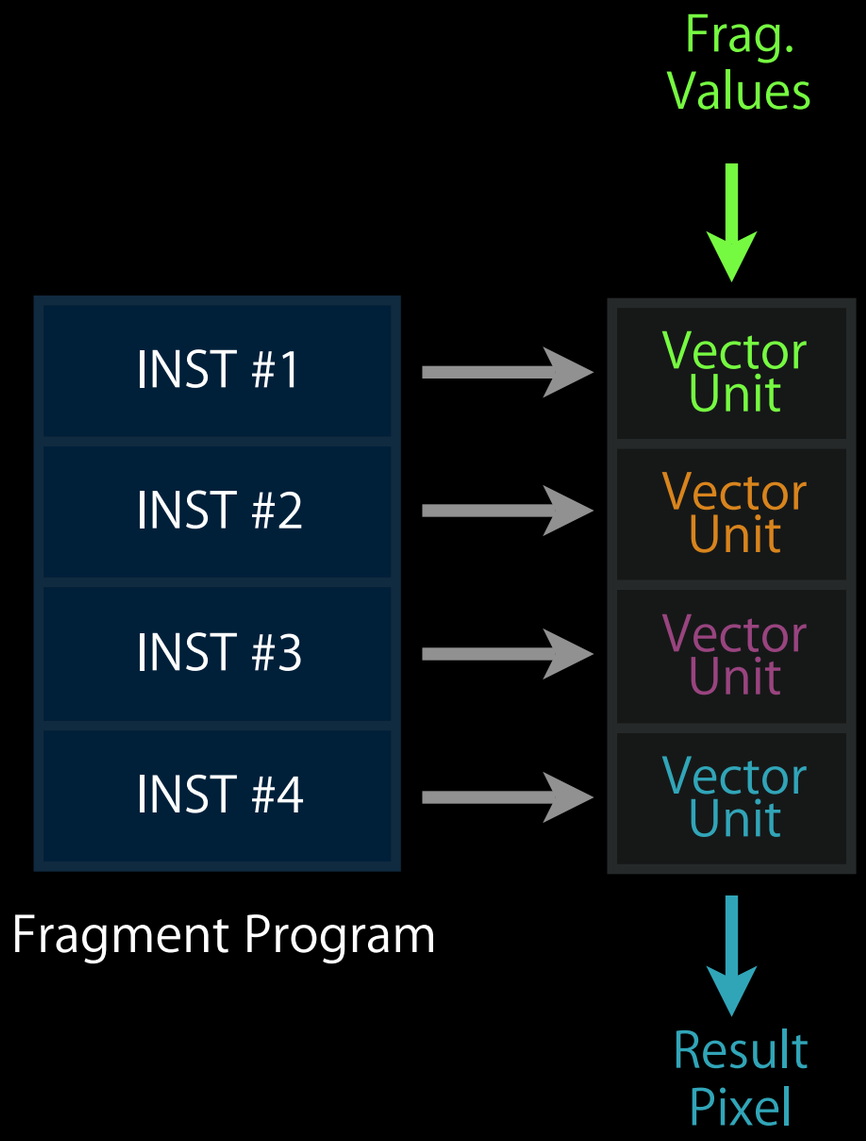

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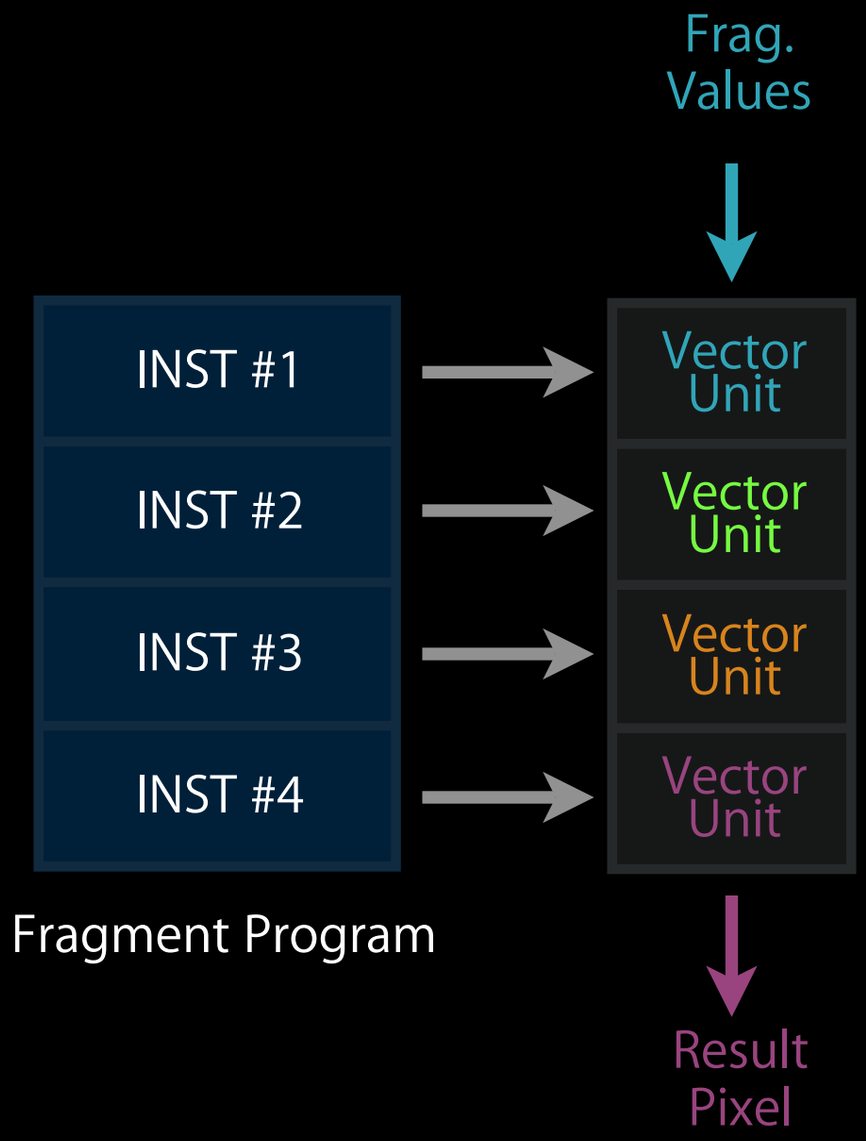

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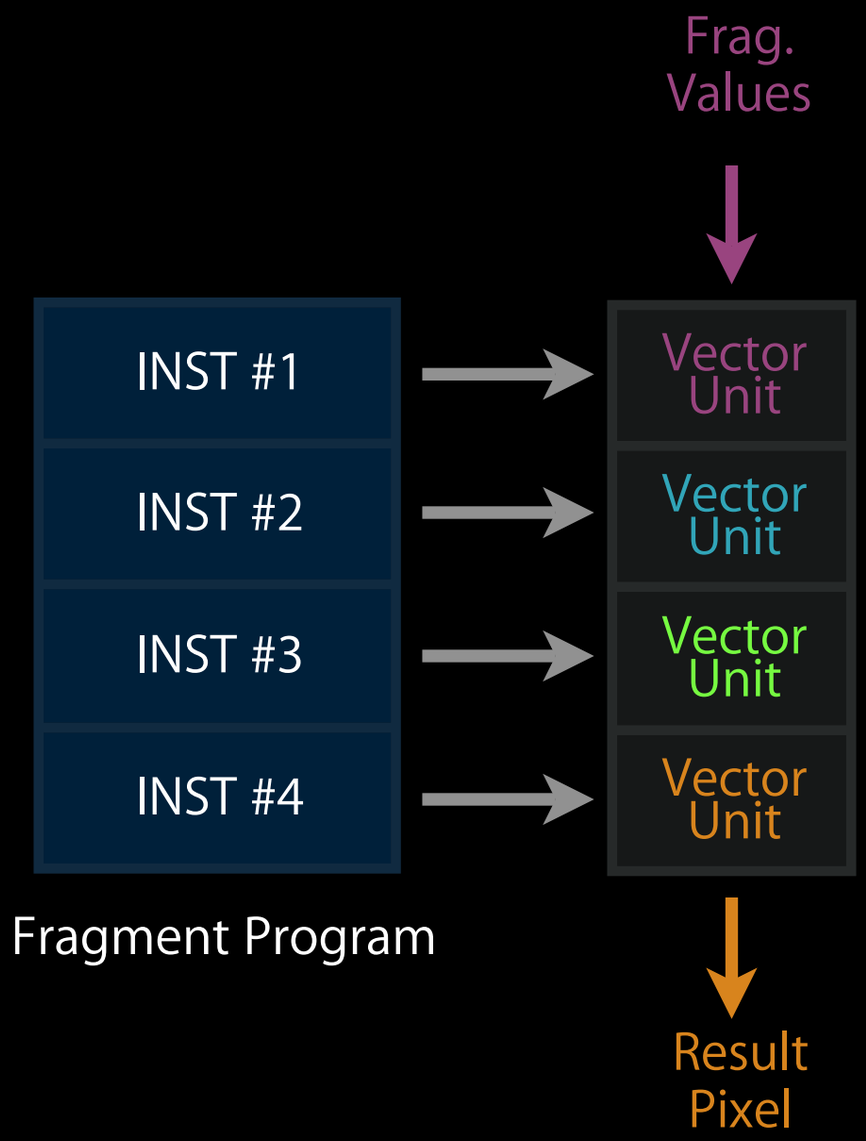

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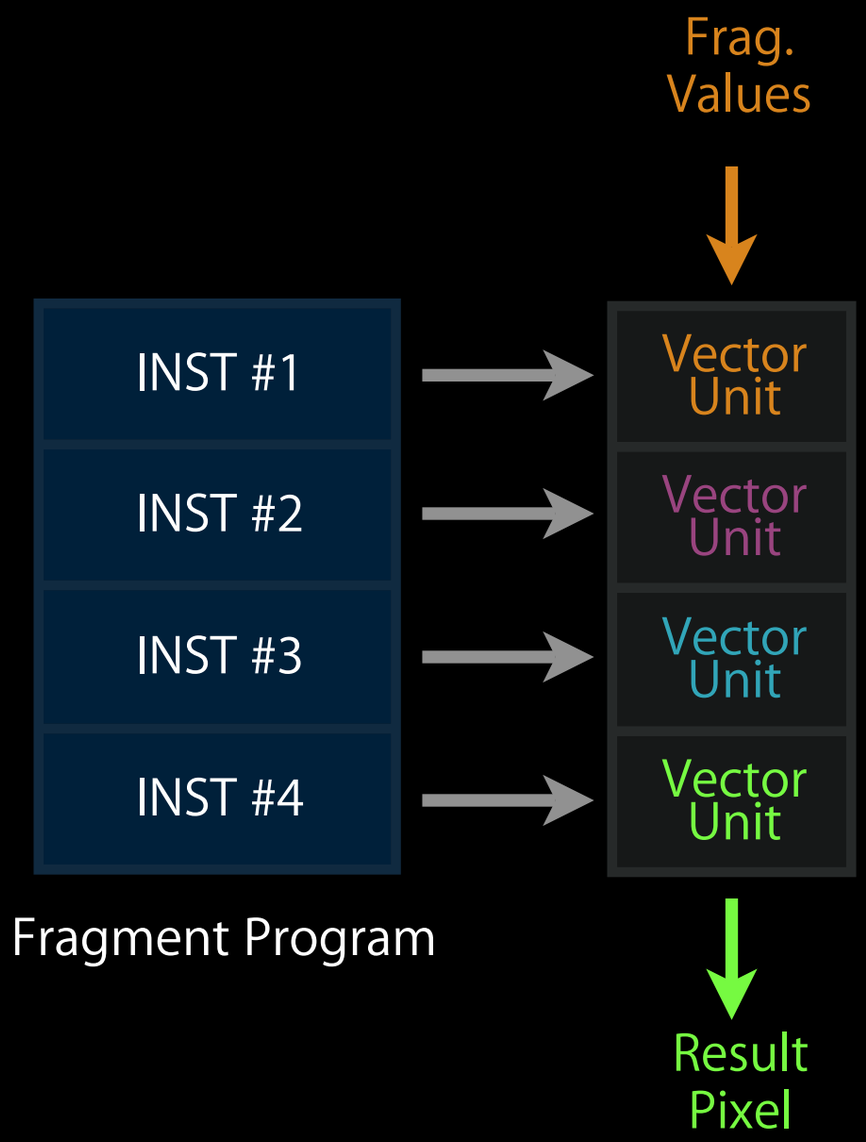

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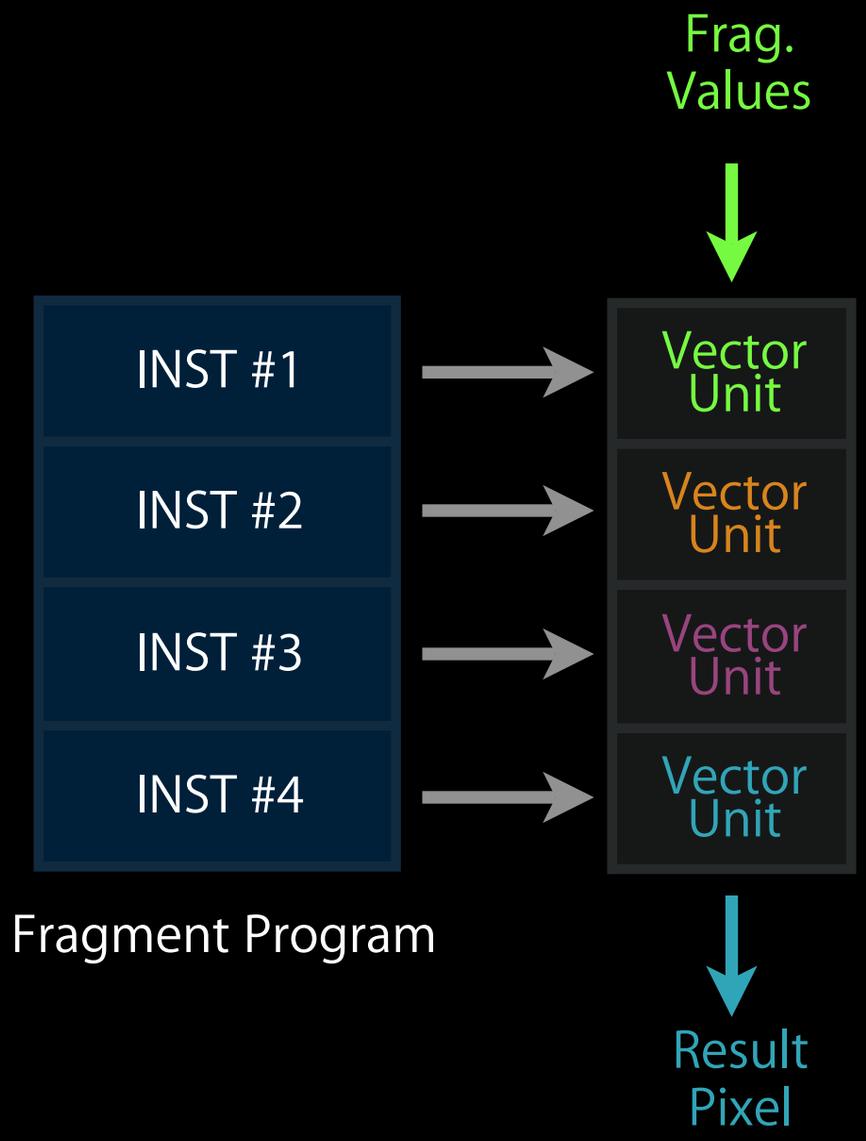

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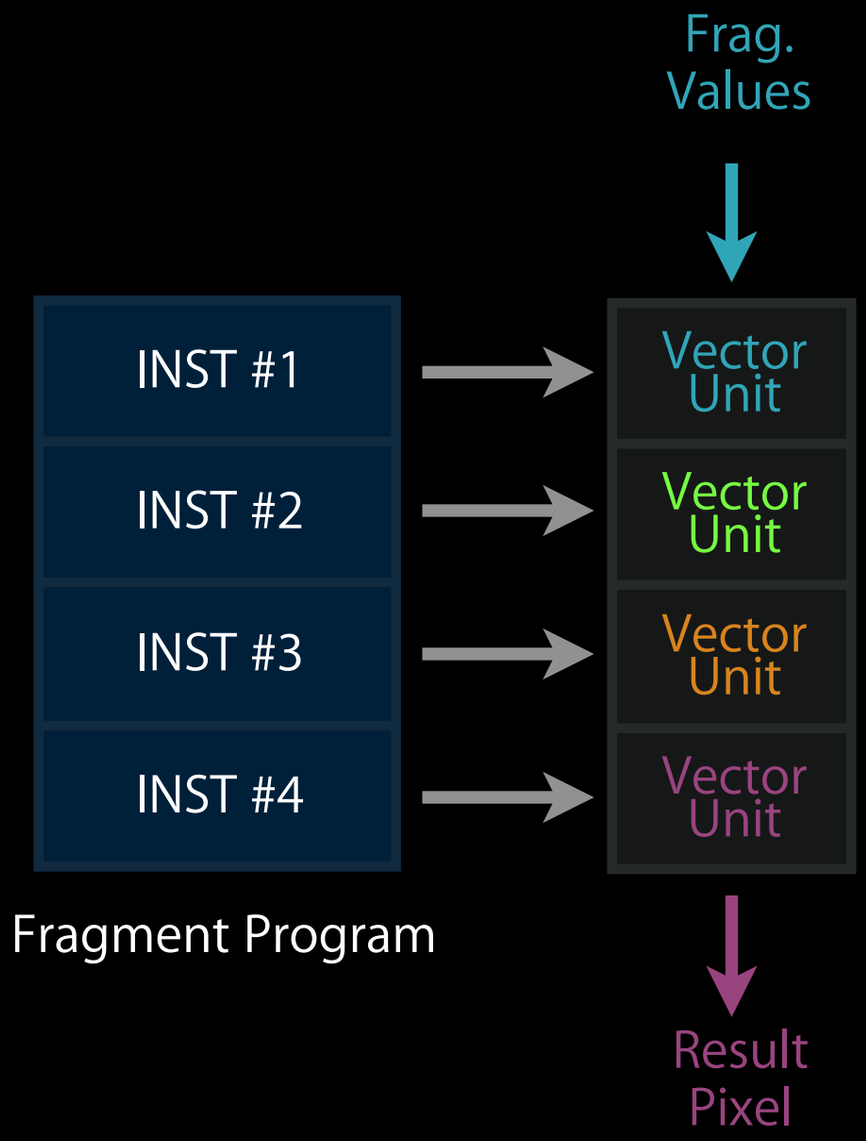

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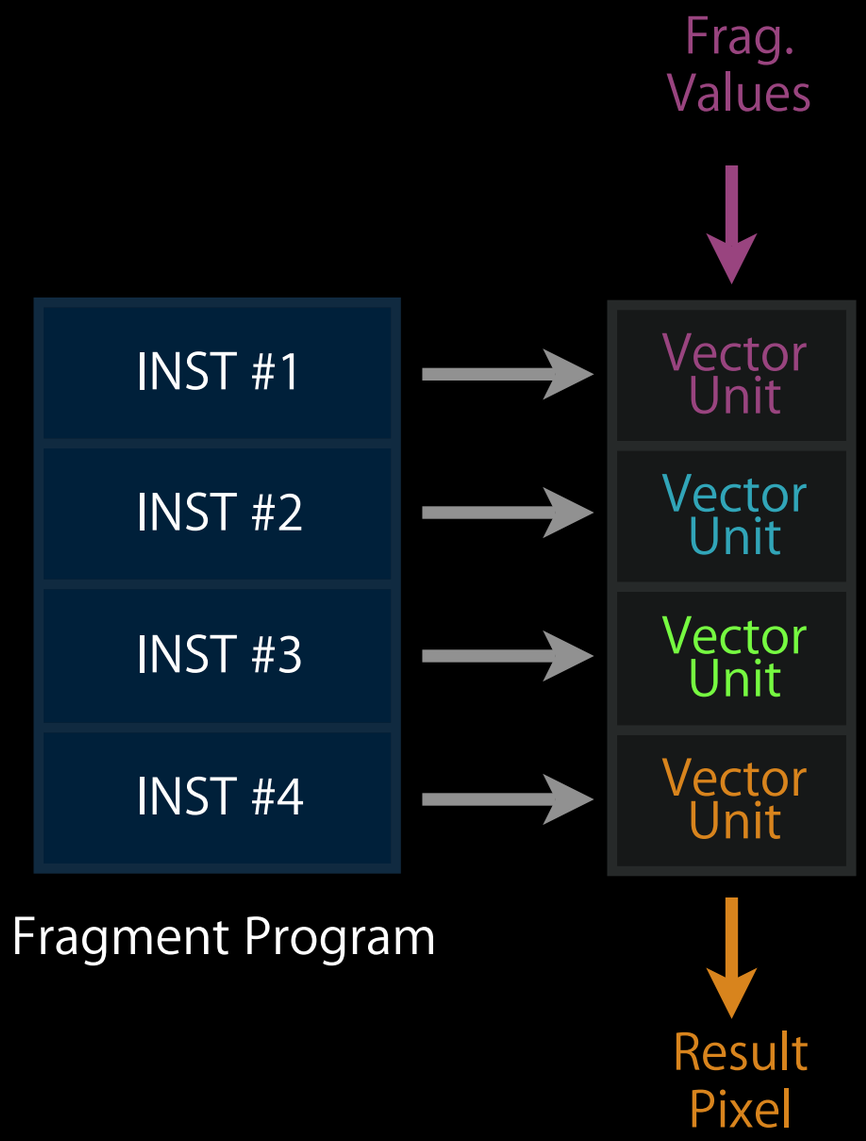

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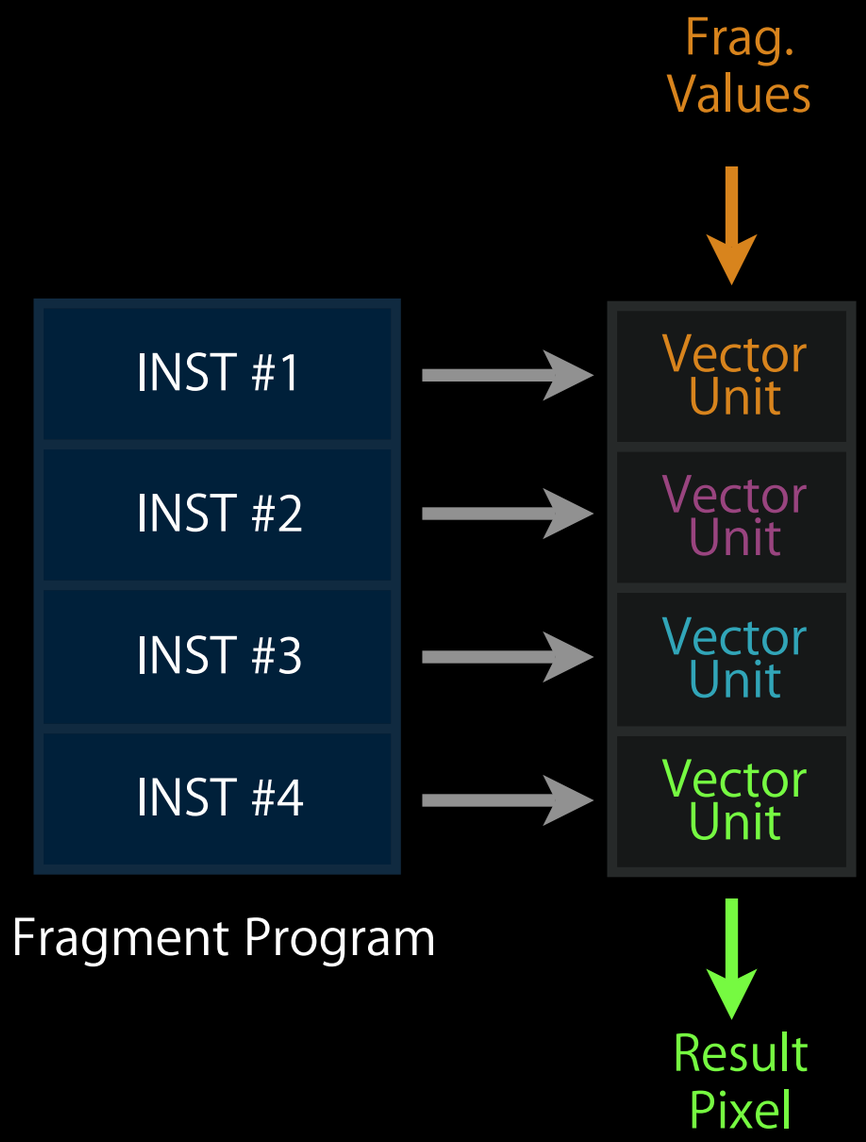

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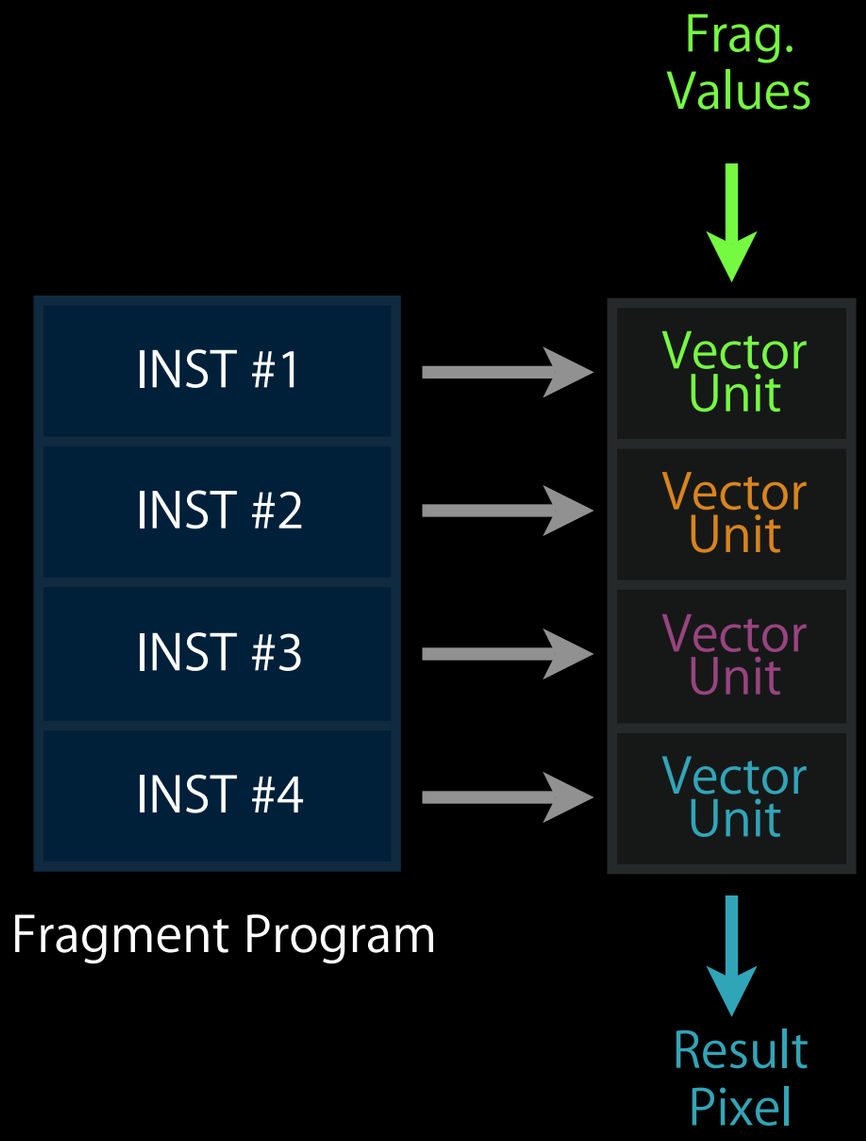

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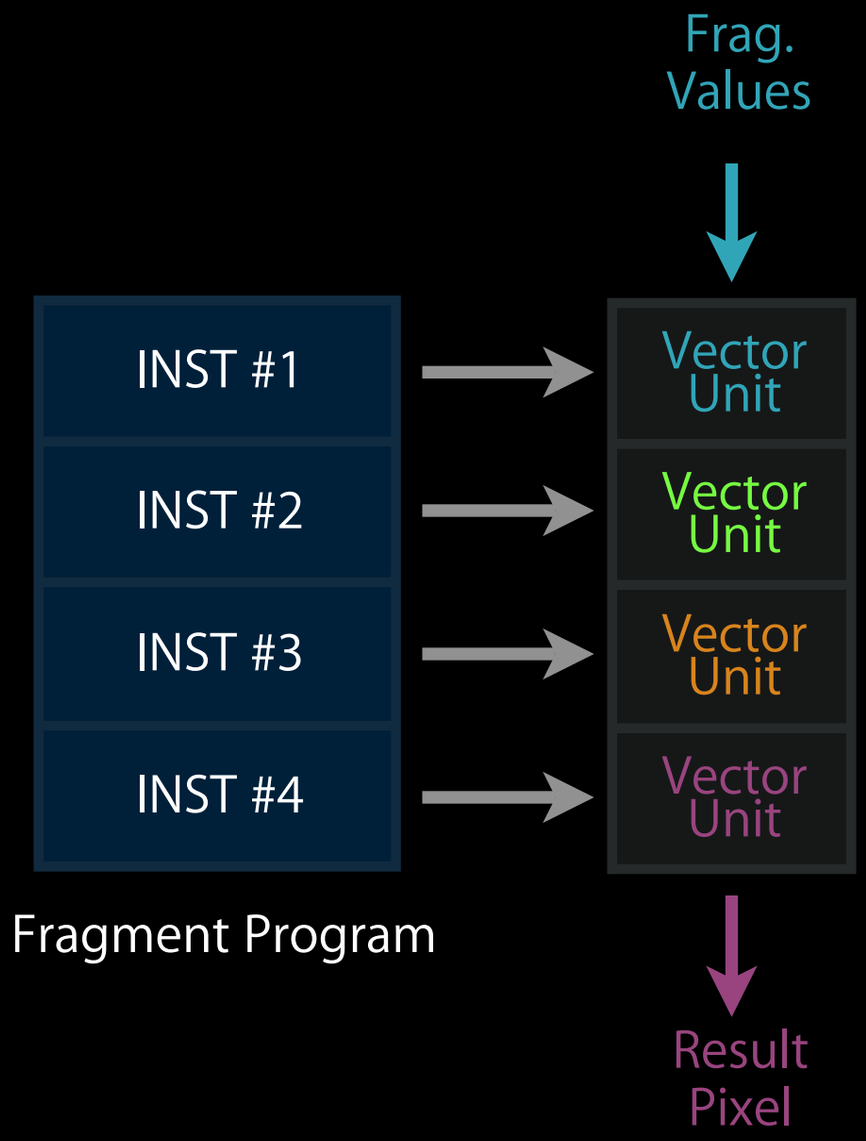

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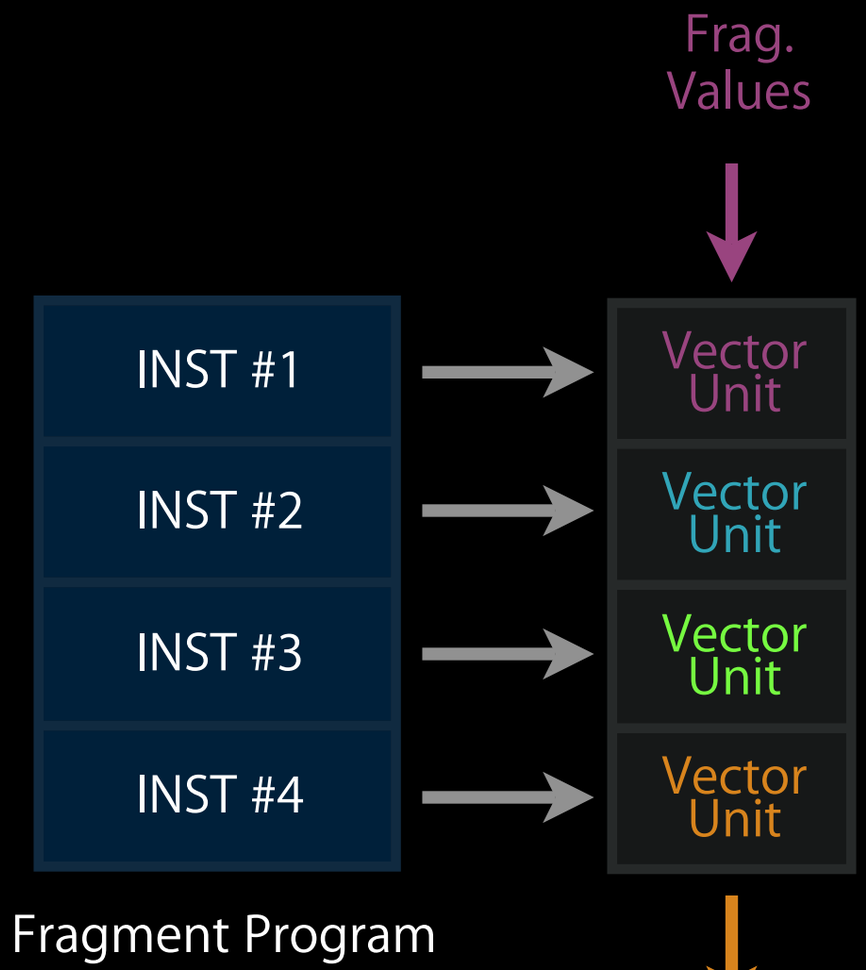


4 vector operations per clock

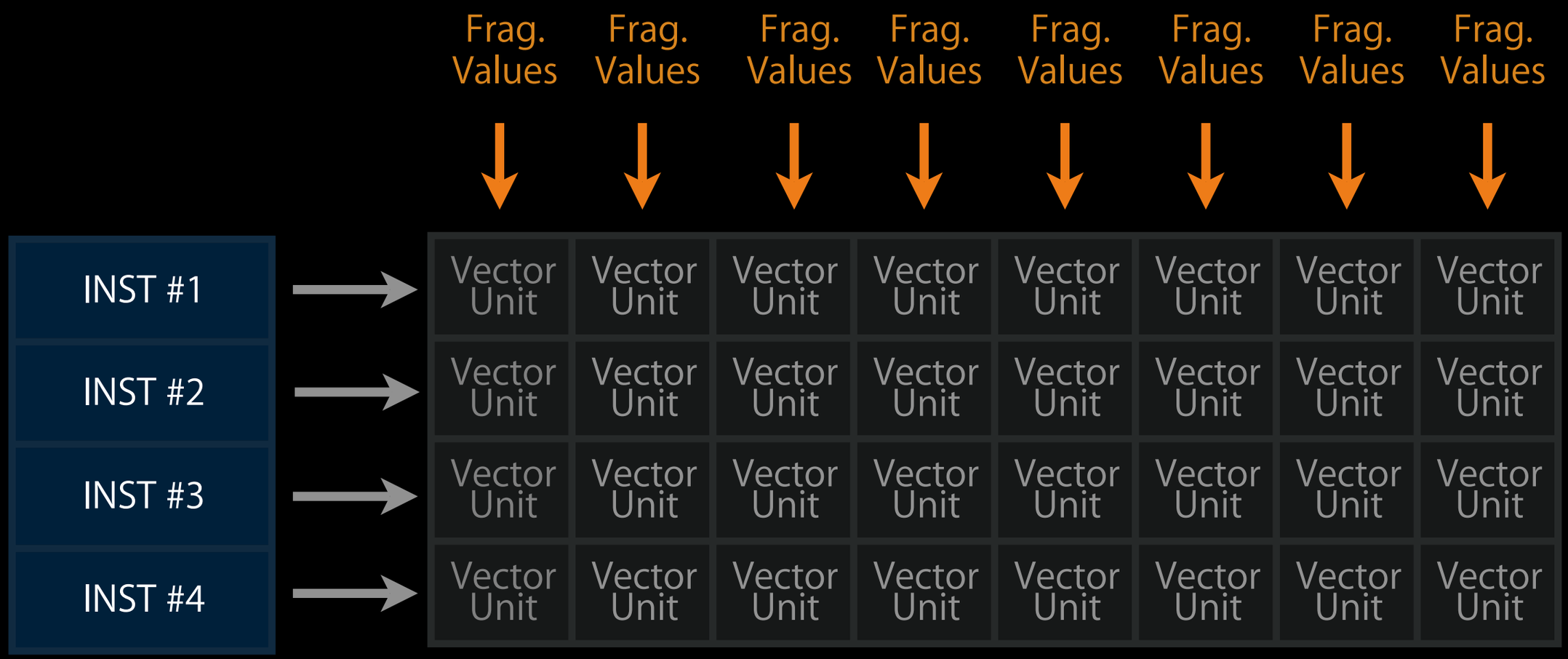
1 result every clock

Putting It Together

- Instruction level parallelism and data parallelism are independent
- Can exploit both at the same time

Parallel Processing

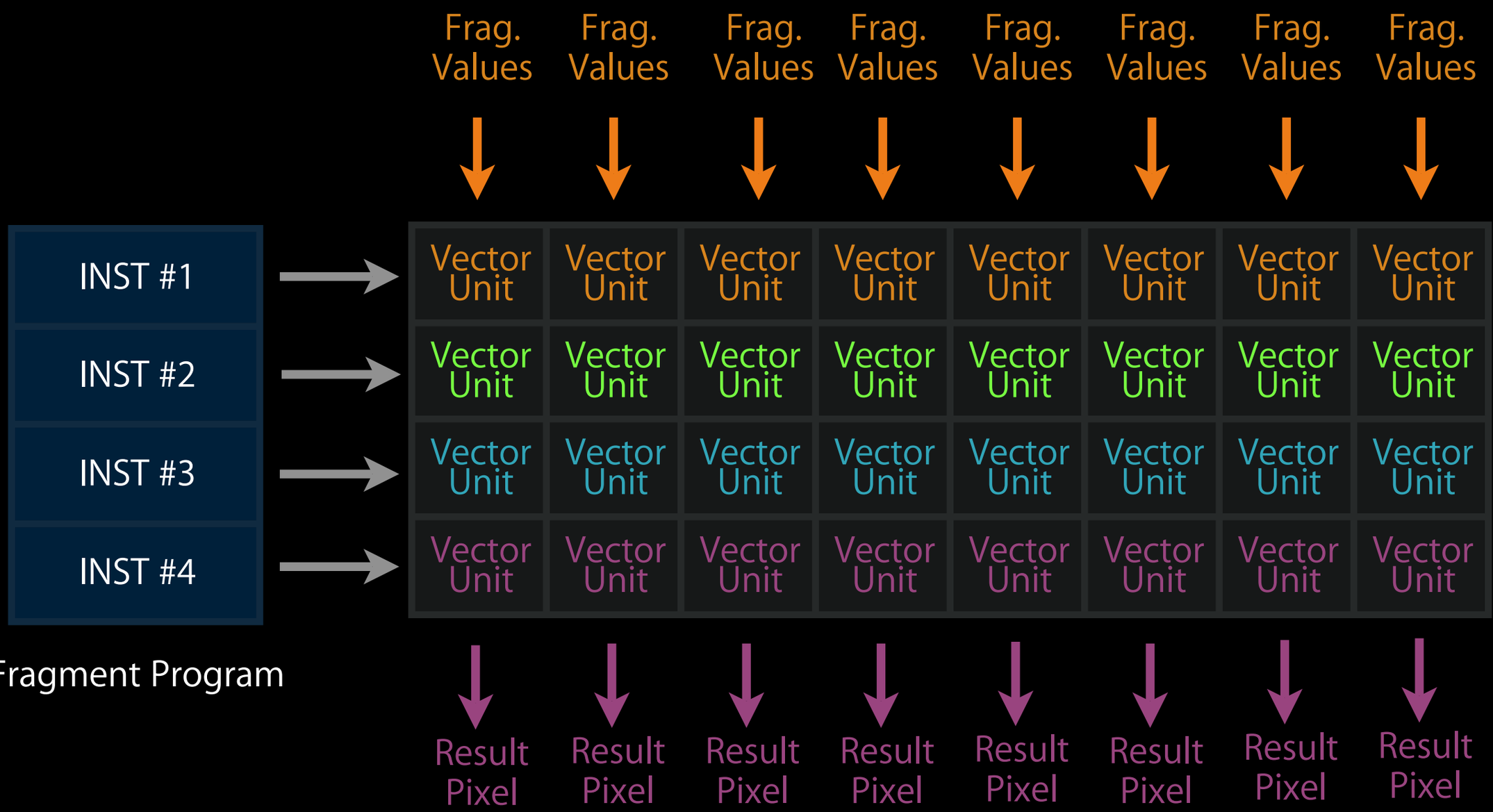
Parallelism allows wide, pipelined execution



Fragment Program

Parallel Processing

Parallelism allows wide, pipelined execution



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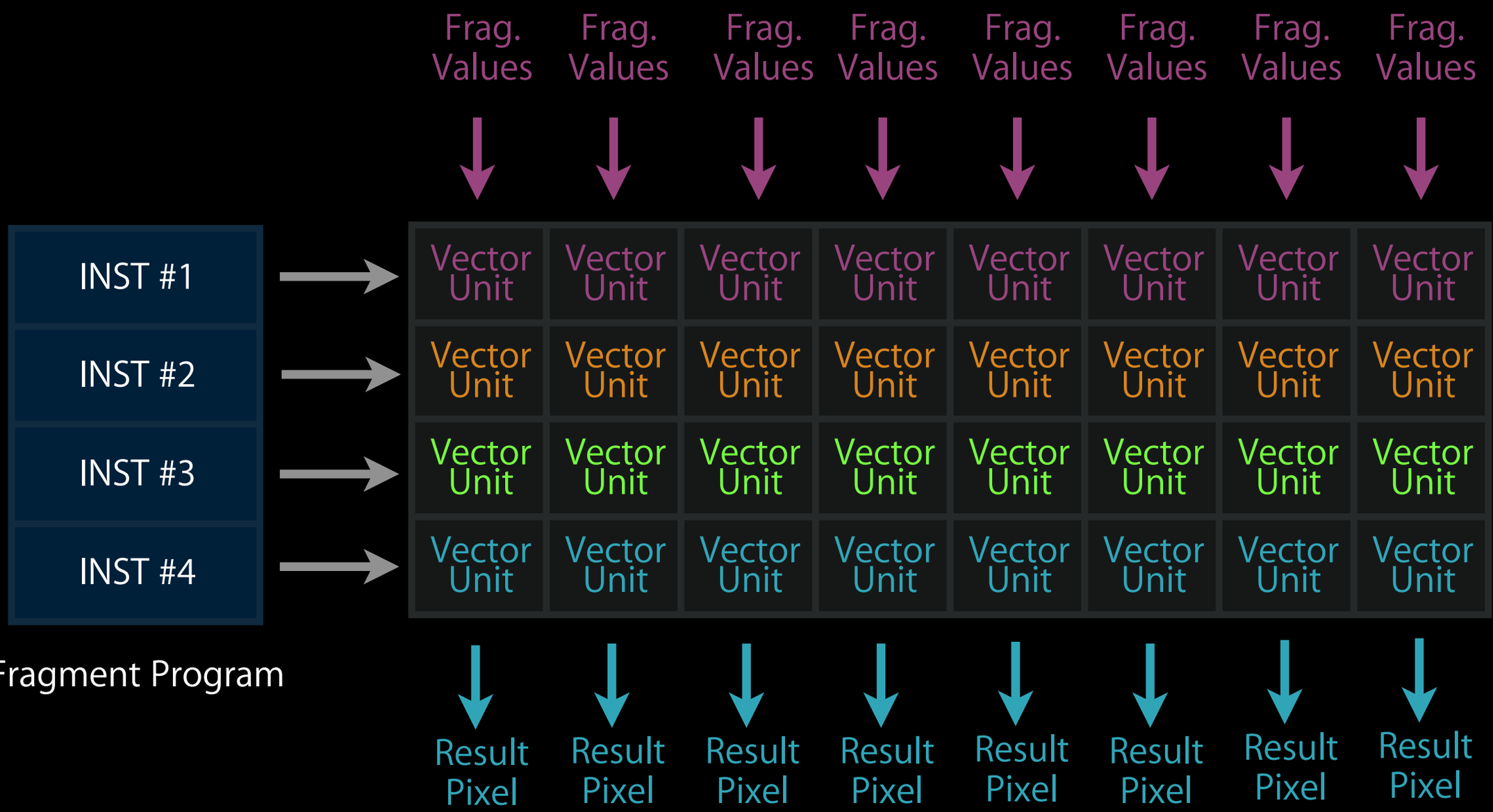

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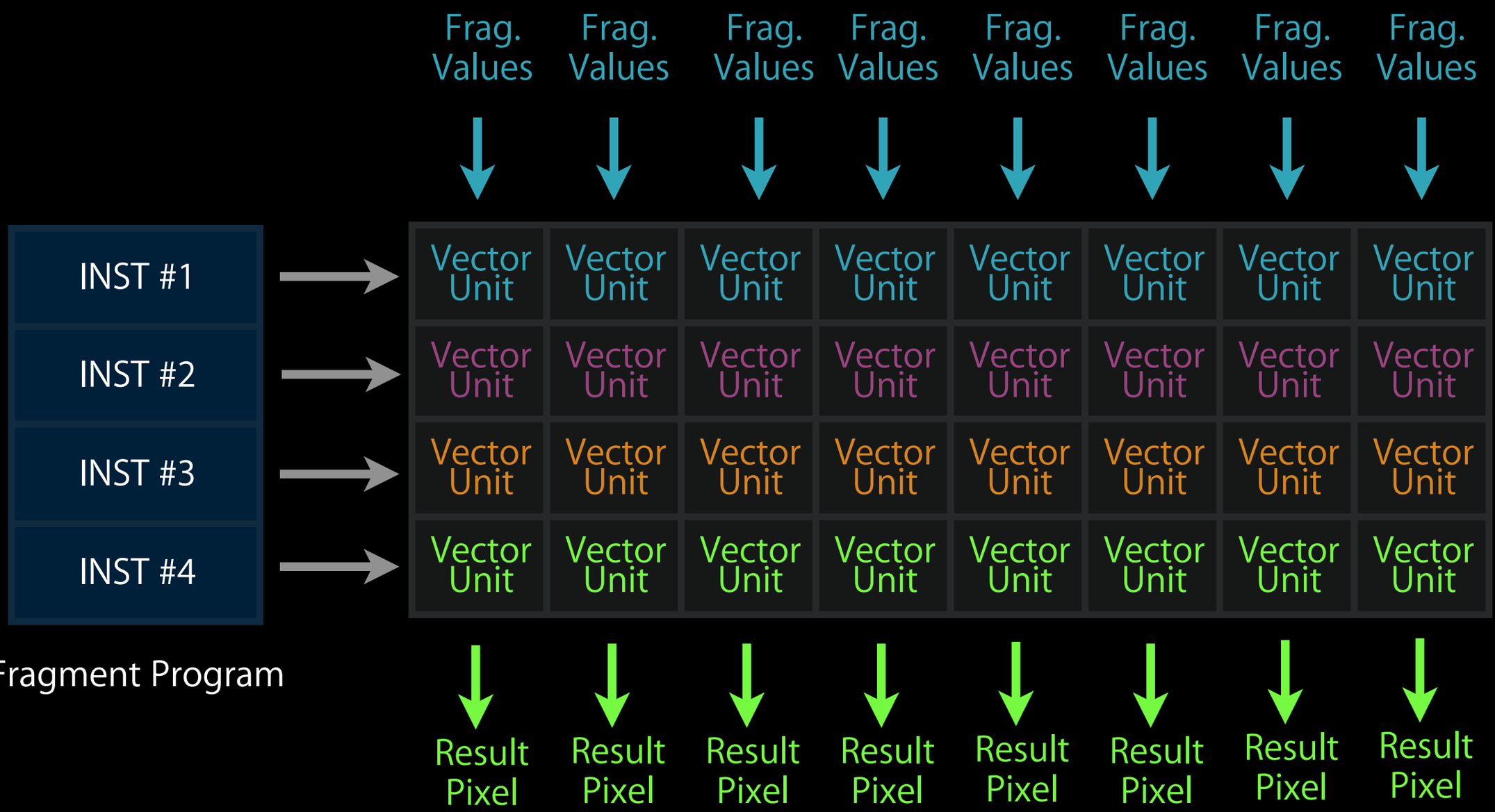

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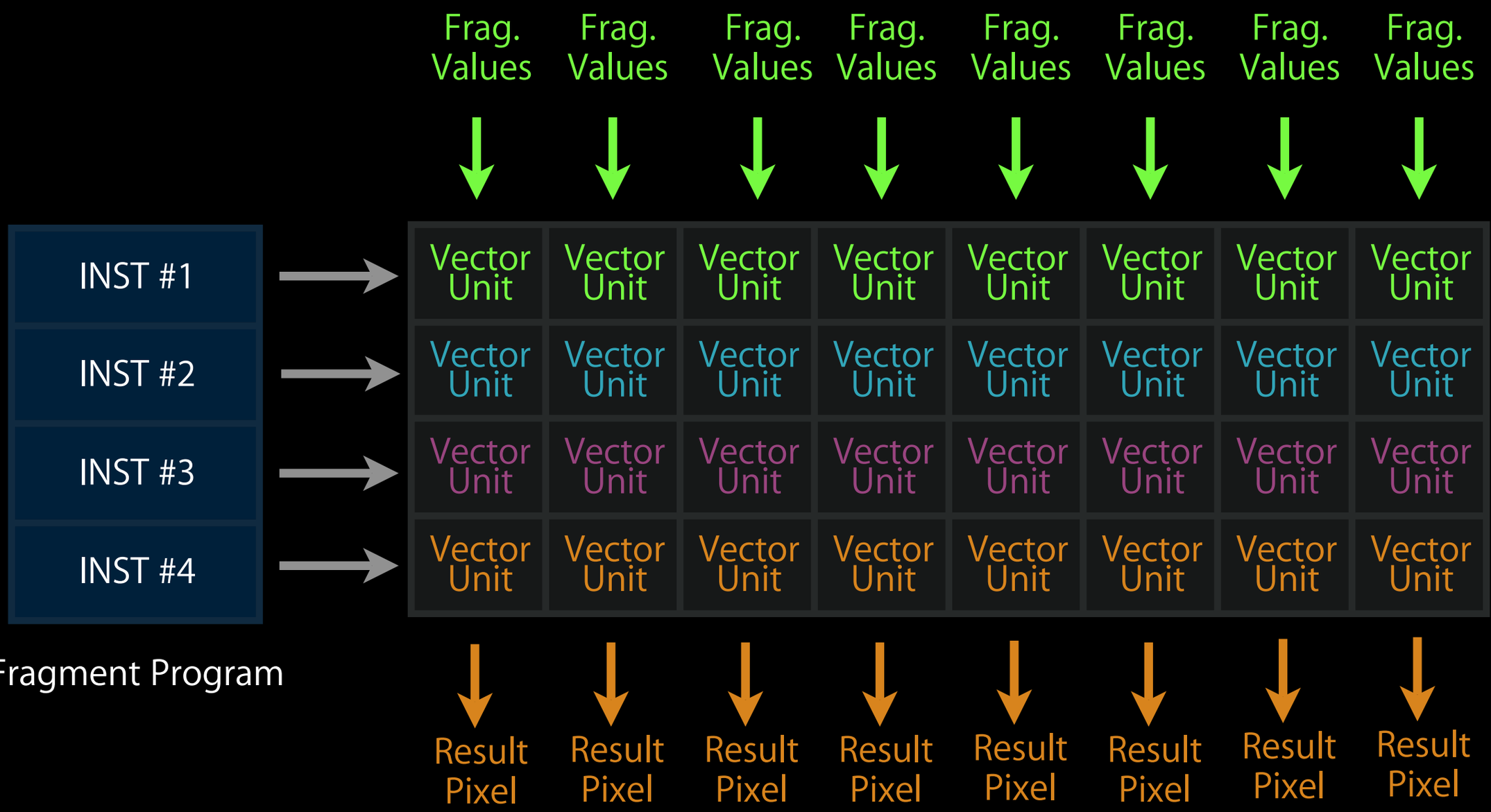

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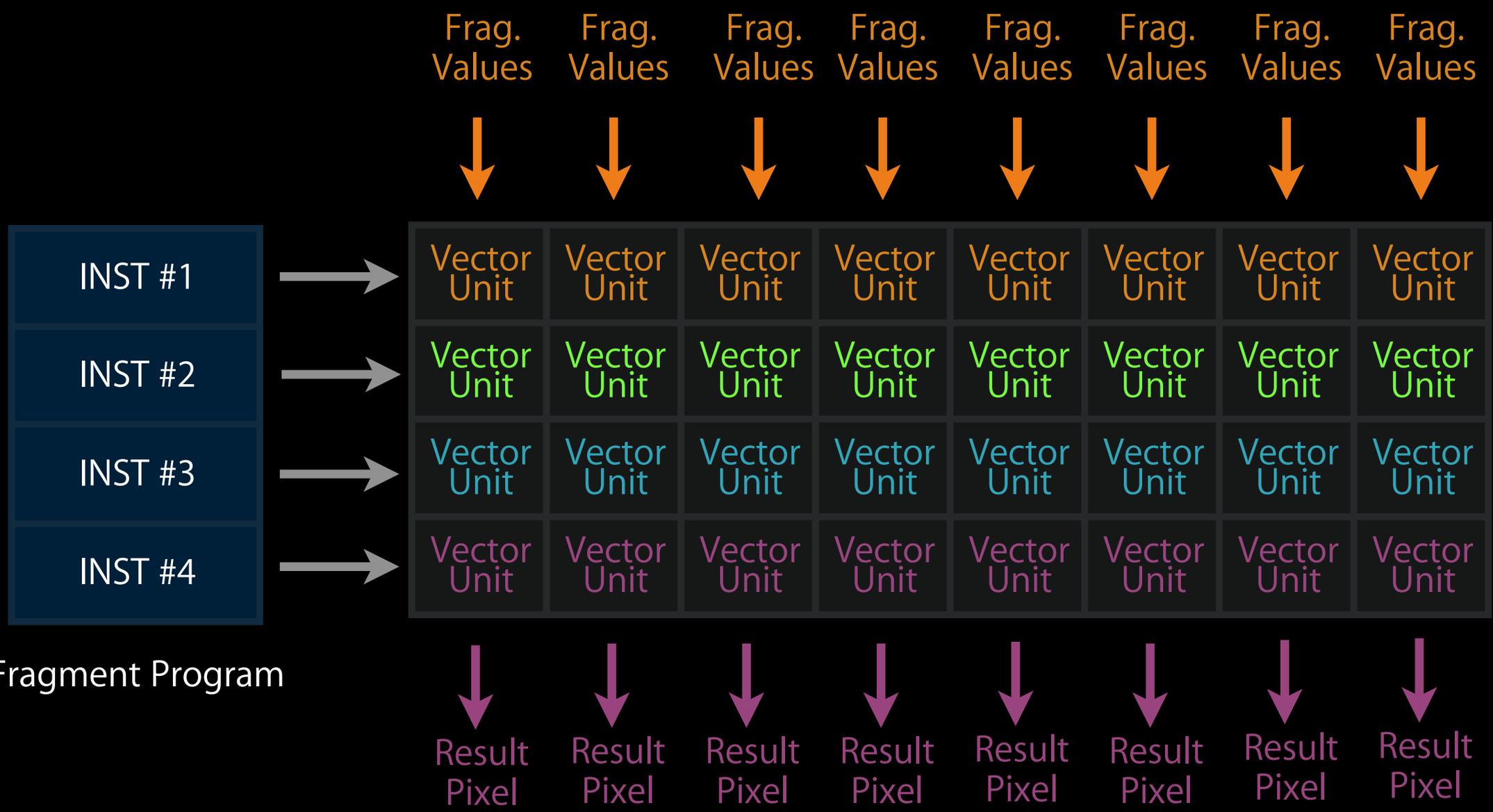

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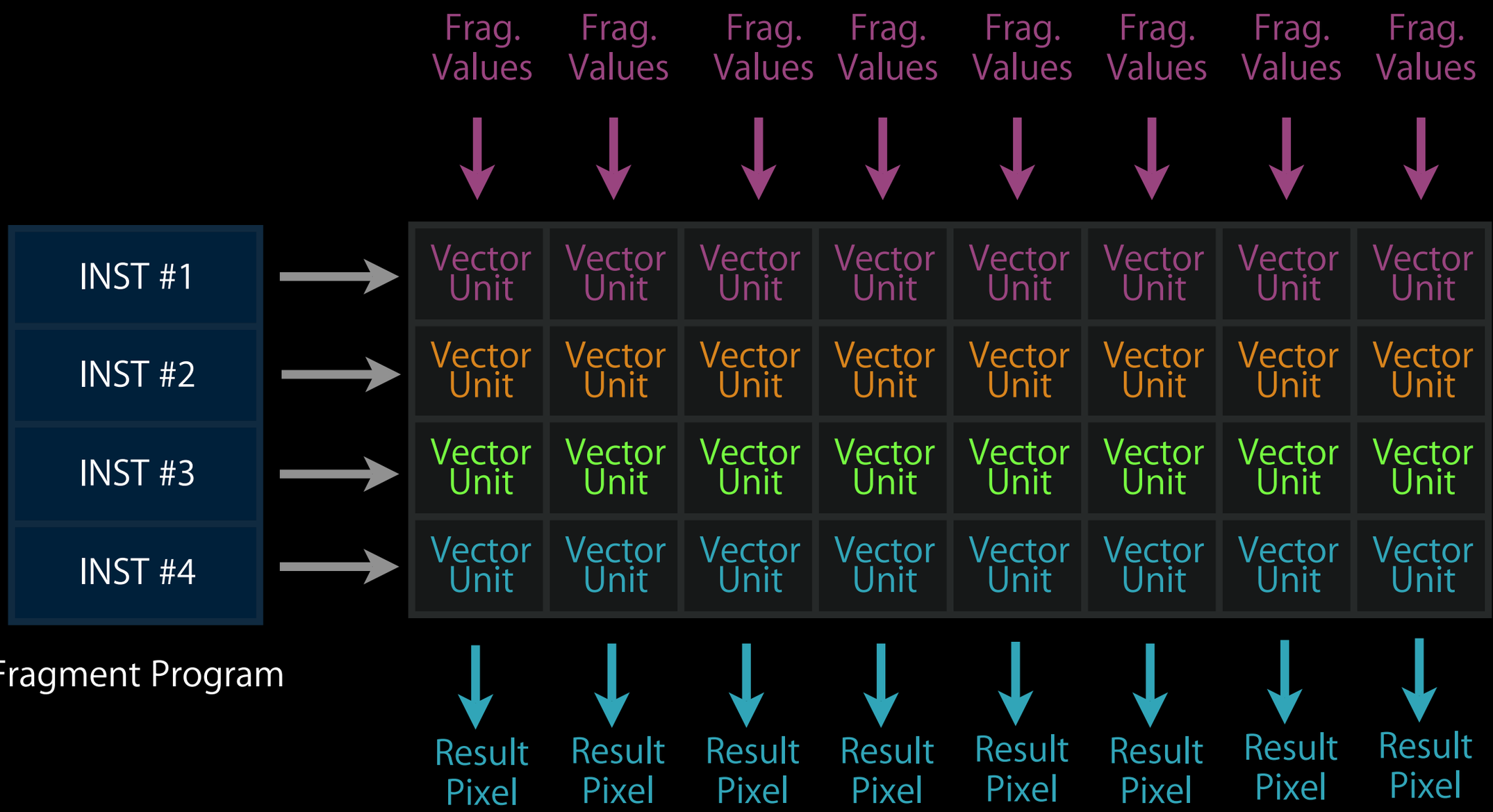

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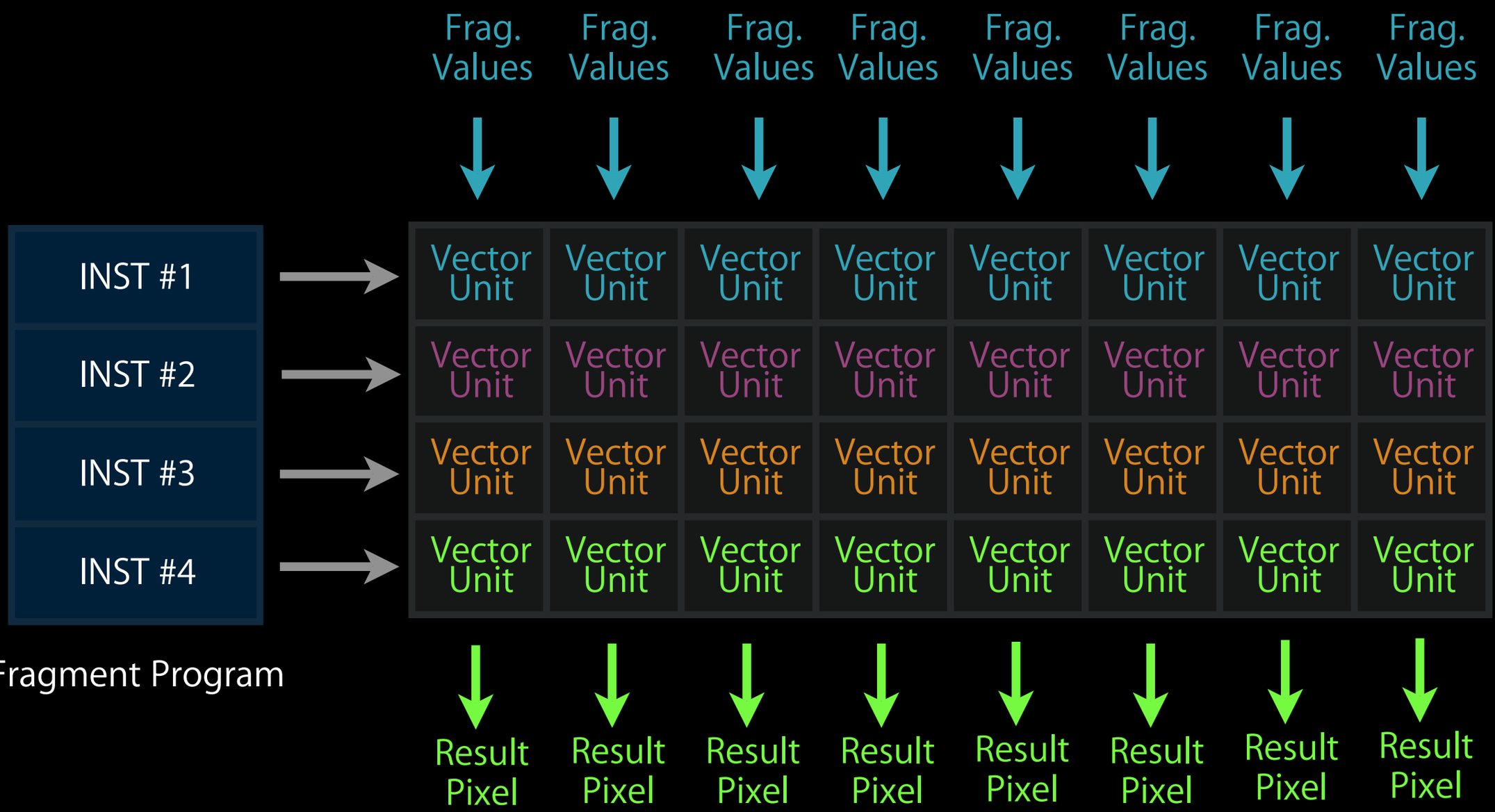

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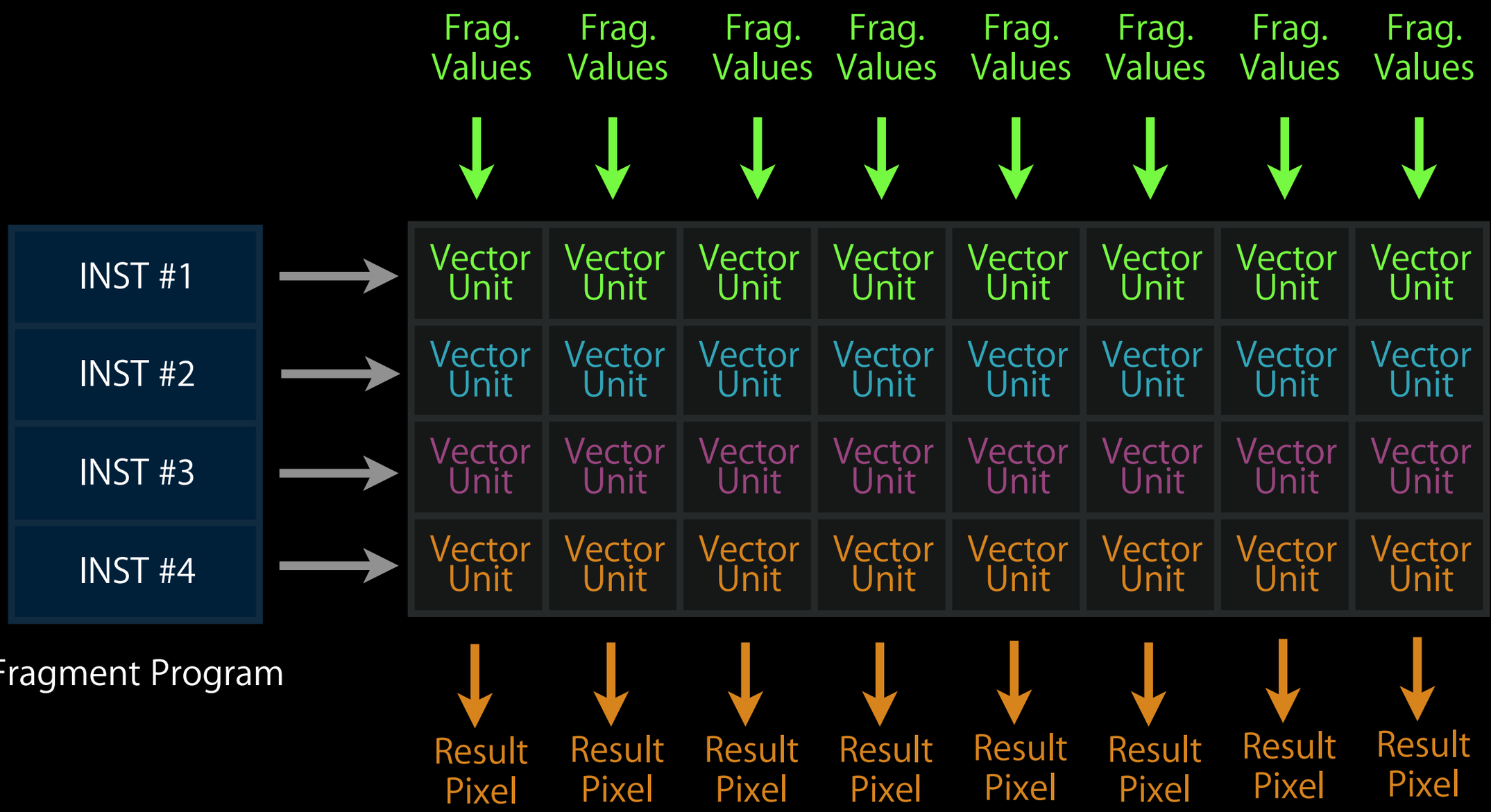


Parallel Processing

Parallelism allows wide, pipelined execution

Fragment Program

32 vector operations per clock
8 results every clock

Will It Sustain?

- Chip capability has not peaked
- Parallel Computing possibilities have not peaked
  - 8x4 in space-time has lots of headroom
- Entertainment demand has (probably) not peaked
- Pour the gasoline on!
  - Operating Systems and applications are adding fuel to the fire!

How Do I Program the GPU?

- Use OpenGL
- Standard cross-vendor programming languages
  - `ARB_vertex_program`
  - `ARB_fragment_program`
- Eventually higher level languages…
- … But “assembly-level” programming will always be available

Demo

Fun with Fragment Programming

Summary

- GPUs have an advantage over CPUs for certain classes of data-parallel algorithms
- This advantage is sustainable for the foreseeable future
- You can access this power via OpenGL
- Learn how you can use this stuff before your competitors do :-)

Quartz 2D on OpenGL

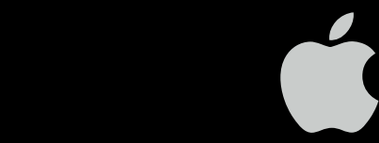
Quartz 2D on OpenGL

- Accelerates Quartz 2D with OpenGL
- Logical next step after Quartz Extreme
- Ties together 2 key thrusts of Mac OS X graphics
- Panther will have initial implementation
- Targeted mainly at OpenGL developers wanting high performance 2D on a OpenGL context

Quartz 2D on OpenGL

```
CGContextRef CGGLContextCreate(CGLContextObj glContext,
          CGSize size, CGColorSpaceRef colorspace);
```

- High-quality 2D rendering
- Virtually identical to software quality
- 2–10x faster than Quartz 2D software rendering
- Quartz quality text cached on textures
- For maxiumum performance, reuse objects
  - CGImageRefs, CGPatternRefs, CGColorRefs
  - Implementation will cache these in video memory



Quartz 2D on OpenGL Limitations

- Certain Quartz 2D operations are not yet supported
  - LCD Text (requires fragment programming)
  - PDF 1.4 blend modes
- CoreGraphics API only
  - No QuickDraw
  - No high-level frameworks (NSImage, etc.)
- Quartz Extreme capable hardware required
- Apps must revisit assumptions about cheapness of accessing window buffer pixels

A Wide Pipe Is Great, But Reading Back Pixels Is Even More Expensive

Vs.

Demo

Quartz 2D on OpenGL

Recap

- New era of innovation in platform graphics
- Mac OS X is a state-of-the-art visual computing platform
- Apple is leading the industry
- Leverage key infrastructure of Quartz 2D and OpenGL
- Learn a few new tricks!

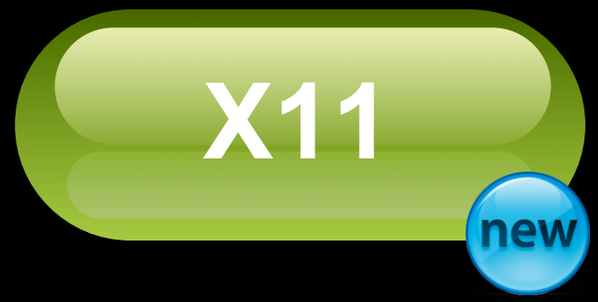
New for Panther

- PDF 1.4 support
- PDF introspection API
- Quartz Scripting—Python Bindings
- CMYK rendering context
- Numerous performance optimizations
  - Text rendering, gradients, printing
- Quartz 2D on OpenGL

New for Panther

207: Quartz 2D In Depth	Presidio Thurs, 9:00am
211: Intro to Quartz Services	Pacific Heights Fri., 9:00am

New for Panther



- XFree86 4.3 Merge
- Double-clickable X11 applications
- Full-screen mode
- Bug fixes

New for Panther

- PostScript support
  - Enables printer sharing with other OSs
- User interface improvements
- Job submission APIs
- CUPS 1.1.19
- CUPs drivers are 1st class citizens
  - gimp-print drivers are in Panther

New for Panther

210: Mac OS X Printing Update

Mission
Thurs., 3:30pm

New for Panther

- End-to-end Color Management by default
  - Cameras embed default profile
  - QTGraphicsImporter applies profile by default
  - CUPS & gimp-print drivers integrated with ColorSync
- Quartz PDF Filters
- Sips—command-line image processing tool
- New APIs for abstract profile generation
- New display calibrator

New for Panther

206: ColorSync Update

Mission
Wed, 5:00pm

New for Panther

- New ways to integrate your app with ImageCapture
  - Automatic Task
  - ImageCapture Services
  - Common UI Layer
- Network support for Image Capture devices
  - Device Sharing and Monitoring

New for Panther

204: Image Capture Update

Marina
Wed., 9:00am

New for Panther

- Fragment programming
- PixelBuffer support
- glCopyTexImage, glTexSubImage optimizations
- Recoverable GPU support
- OpenGLShaderBuilder enhancements
- OpenGLProfiler enhancements
- Use Quartz 2D in a OpenGL context
- Lots of bug fixes and optimizations

New for Panther

201: Mac OS X OpenGL In Depth	Nob Hill Tues., 2:00pm
205: Vertex Programming With OpenGL	Marina Wed., 3:30pm
208: Fragment Programing With OpenGL	Pacific Heights Thurs., 10:30am
209: OpenGL Optimizations	Marina Thurs., 2:00pm
212: Cutting Edge OpenGL Techniques	Russian Hill Fri., 2:00pm

Special Session:
Technology Magic of Keynote

Nob Hill, Tuesday, 3:30pm

Feedback

FF018: Graphics and Imaging Feedback Forum

North Beach
Friday, 5:00pm

WWDC 2003

Worldwide Developers Conference